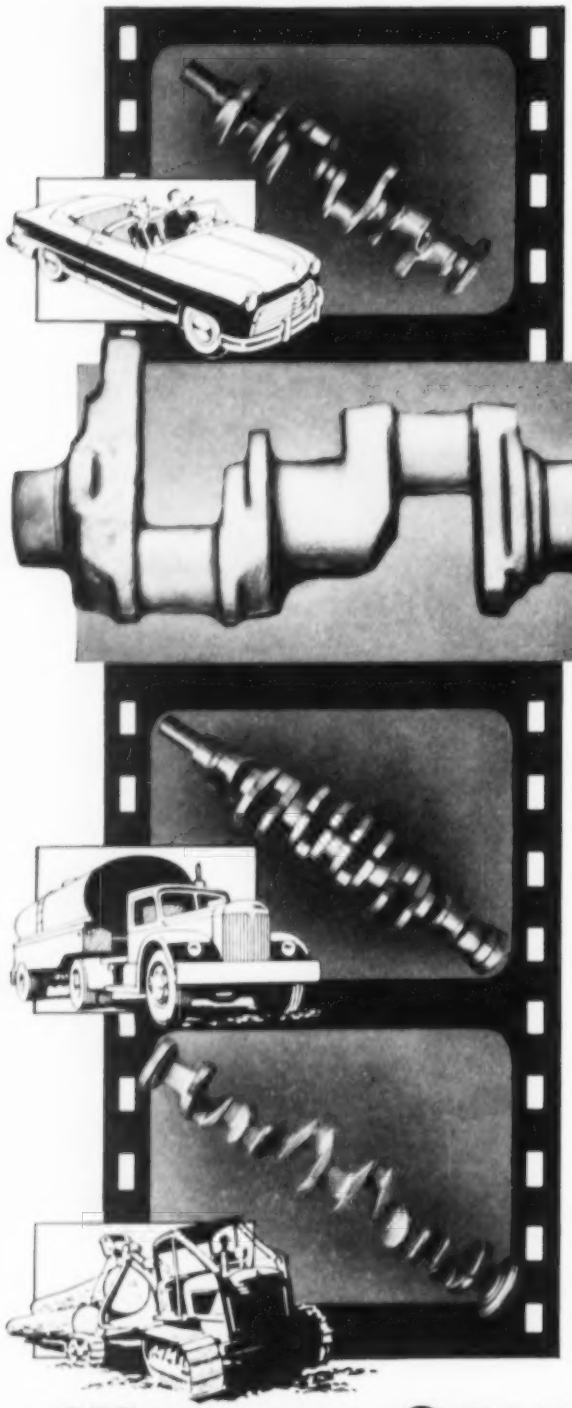
JOURNAL OF

METALS

MARCH 1957



There's no substitute for the FORGED crankshaft

Crankshafts have been made successfully by other methods of fabrication and have proven to be *good enough* for certain non-critical applications—but for maximum dependability of the modern, compact, high compression, high torque engine a forged crankshaft is essential.

The forging process assures, to the greatest degree possible, uniformity and predictability of physical properties with a minimum variance from piece to piece or from one location to another in the same piece.

Wyman-Gordon has been forging crankshafts since the beginning of the internal combustion engine era and today produces more crankshafts for a greater variety of applications than any other company in the world. In a crankshaft there is no substitute for a forging, and in a forging there is no substitute for Wyman-Gordon quality and experience.

WYMAN-GORDON COMPANY

Established 1883

WORCESTER 1, MASSACHUSETTS
HARVEY, ILLINOIS • DETROIT, MICHIGAN

FORGINGS OF ALUMINUM • MAGNESIUM • STEEL • TITANIUM

JOURNAL OF

METALS

VOL. 9, NO. 3

MARCH 1957

Published to provide a continuing, authoritative, and up-to-date record of technological, engineering, and economic progress in all branches of the industry by the Metallurgical Society, American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., 29 West 39th Street, New York 18, N. Y.

EDITORIAL STAFF

RIXFORD A. BEALS
Editorial Director

F. WESTON STARRATT
Associate Editor

JAMES J. BURKE
N. FRANKEL H. WITZLING
Assistant Editors

M. SNEDEKER
Production Editor

ADVERTISING STAFF

GRACE PUGSLEY Production Manager
W. J. SEWING Asst. Prod. Mgr.

THOMAS G. ORME
Eastern Advertising Manager

BOB WILSON
Western Advertising Manager
Millard Ave., Fox River Grove, Ill.

SOCIETY OF METALLURGICAL ENGINEERS

J. C. Kinnear, Jr. — President
A. W. Thornton — Past-President
W. R. Hibbard, Jr. — Vice President
R. W. Shearman — Secretary-Treasurer

BOARD OF DIRECTORS

J. B. Austin, D. L. Clark, H. B. Emerick, T. D. Jones, H. H. Kellogg, C. T. Marshall, E. E. Schumacher, C. S. Smith, J. D. Sullivan

SOCIETY PUBLICATIONS COMMITTEE

J. S. Smart, Jr., Chairman
J. B. Austin, John Chipman, Gerhard Derge, S. J. Dickinson, G. R. Fitterer, W. J. Harris, Jr., J. H. Hollomon, H. H. Kellogg, P. T. Stroup

DIVISION PUBLICATIONS COMMITTEE CHAIRMEN

G. Derge — Iron and Steel
H. H. Kellogg — Extractive Metallurgy
C. E. Birchenall — Institute of Metals

The AIME Publishes:

Journal of Metals
Mining Engineering
Journal of Petroleum Technology

COVER

Heat, pressure, and powder: Irene Trivas has combined these three elements in this month's cover, which symbolizes the 1957 Powder Metallurgy Symposium, presented on page 325. The proceedings of the 1956 Symposium will be found in the Transactions section, starting on page 349.

FEATURES

Personnel	310	AIME News	381
Books	321	Personals	386
Reporter	317	Coming Events	388D
Drift	323	Advertisers Index	388D

POWDER METALLURGY SYMPOSIUM—1957

Introduction — F. V. Lenel — 325

Metallic Filters by Powder Metallurgy — J. Haertlein — 326

High Strength Structural Parts by Powder Metallurgy

- Theory — H. H. Hausner — 331
- Techniques — G. Stern — 334
- Applications — J. M. Copeland — 336

TECHNICAL ARTICLES

Ferromanganese From Low-Grade Ores — J. J. Burke — 340

Cobalt Pressure Leaching and Reduction at Garfield — J. S. Mitchell — 343

Nonferrous Research Uses Solar Furnace — W. M. Tuddenham — 346

TRANSACTIONS

Powder Metallurgy Symposium—1956
Dispersed Hard Particle Strengthening of Metals — N. J. Grant and O. Preston — 349

Cominco's New Sinter Plant — E. A. Mitchell, J. F. Melvin, and R. Bainbridge — 361

Comparison of Blast Furnace Penetration with Model Studies — J. B. Wagstaff and W. H. Holman — 370

Differential High-Temperature Sulfatization of Cuyuna Manganese Ore — C. Prasky — 377

TECHNICAL NOTE: X-Ray Microscopy of As-Grown and Deformed Single Crystals of Aluminum — J. H. Auld, R. A. Coyle, A. M. Marshall, and N. A. McKinnon — 360

Published the first day of each month by the American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., 29 West 39th Street, New York 18, N. Y. Telephone: PEnnsylvania 6-9220. Subscription $6 per year for non-AIME members in United States and North, South, and Central America; $10, foreign; $6 for AIME members; or $4 additional in combination with a subscription to "Mining Engineering" or "Journal of Petroleum Technology." Single copies, 75 cents; single copies foreign, $1.00; special issues, $1.50. The AIME is not responsible for any statement made or opinion expressed in its publications. Copyright 1957 by the American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc. Registered cable address, AIME New York. Indexed in Engineering Index, Industrial Arts Index, and Chemical Abstracts. Second class mail privileges authorized at New York, N. Y., and additional entry established at Manchester, N. H. Number of copies of this issue 10,000.

PERSONNEL

THE following employment items are made available to AIME members on a non-profit basis by the Engineering Societies Personnel Service, Inc. (Agency) operating in cooperation with the Four Founder Societies. Local offices of the Personnel Service are at 8 W. 40th St., *New York 18*; 100 Farnsworth Ave., *Detroit*, 57 Post St., *San Francisco*, 84 E. Randolph St., *Chicago 1*. Applicants should address all mail to the proper key numbers in care of the New York office and include 6c in stamps for forwarding and returning application. The applicant agrees, if placed in a position by means of the Service, to pay the placement fee listed by the Service. AIME members may secure a weekly bulletin of positions available for $3.50 a quarter, $12 a year.

MEN AVAILABLE

Metallurgist-Production, B.S., 42. Top supervisory experience in pyro and hydrometallurgy for past 13 years. Presently employed as superintendent of large nonferrous smelter. Desires responsible position in production or development. Will locate in any part of U. S. M-158.

POSITIONS OPEN

Sales Engineer, 30 to 40 preferred, B.S. in metallurgy, with some experience in welding, chemical, or piping fields. Some travel. Salary open. Headquarters, northern New Jersey. W4568.

Assistant to Plant Manager, young, graduate metallurgical engineer, with knowledge of heat treating and manufacturing, to be responsible for shop methods and production welding. Salary, $5000 to $6000 a year. Location, New York. W4560.

Research Engineers, with experience in nonferrous metallurgy, especially the nonferrous extractive metallurgy of lead, zinc, and copper; also a few years experience in pilot plant work or in general smelter test work. a) *Metallurgical*, with 5 to 20 years experience, to plan and conduct research on problems of extractive metallurgy. Salary, $8,000 to $12,000 a year. b) *Metallurgical*, with one to five years experience, to conduct research on problems of extractive metallurgy. Will assist more experienced engineers. Salary, $6000 to $9000 a year. Location, western Pennsylvania. W4554.

Assistant General Plant Superintendent, engineering and/or metallurgy degree, with five to ten years experience in production operations, to control and coordinate production activities and to supervise the work of various production departments in ore processing plant. Salary, $8,880 to $13,320 a year. Location, Cuba. F4546.

Metallurgists, 23 to 35, B.S. in chemistry or metallurgy, with approximately two years experience in the light metals field, to perform metallurgical duties in extrusion and possible finishing areas. Salary open. Location, East Coast. W4509.

Ore Dressing Metallurgist, to work on process development and control in a progressive mining operation. Liberal housing and employe benefits. Salary, commensurate with experience. Location, East. W4493(a).

Metallurgist, with about ten years experience in the field of ore dressing. Experience in the nonmetallic flotation field and in particular phosphate rock desired. Salary, open. Location, South. W4492.

Assistant to Sales Manager, with metallurgical training and at least

(Continued on page 312)

Additional classified advertising appears on pages 312 and 314.

Engineering Societies Personnel Service Inc.

(Agency)

Under the auspices of the Four Founder Engineering Societies and affiliated with other renowned Engineering Societies, ESPS offers many years of placement experience in addition to world wide contacts.

New York — 8 W. 40th St.
Chicago — 84 E. Randolph St.
Detroit — 100 Farnsworth Ave.
San Francisco — 57 Post St.

METALLURGISTS: Advanced degree or B.S. with five years experience, for development and research work on a variety of problems related to high-temperature alloys. Unexcelled opportunity for growth in a rapidly expanding Company, with earnings and fringe benefits equal to highest in industry. Moving expenses paid. All replies confidential. Location—Upstate New York. Send resume and salary requirements to:

Box 5 JM AIME
29 West 39th St
New York 18

METALLURGISTS
WELDING ENGINEER

The expanding work of our Metals Research Department offers an exceptional opportunity to work on challenging research and development projects. These openings offer excellent opportunity for professional and personal growth for creative individuals who possess an interest in and knowledge of modern research techniques. Salary is commensurate with training and experience, with liberal benefits including tuition free graduate study and generous relocation allowance. If you have experience in the following areas:

Applied Metallurgy
Extractive Metallurgy
Physical Metallurgy
Foundry
Welding
Alloy Development

send complete resume to:

J. A. Metzger

ARMOUR RESEARCH FOUNDATION

of Illinois Institute of Technology
10 West 35th St.
Chicago 16, Illinois

PROCESS METALLURGISTS

Exceptional opportunities available for engineers trained and interested in Pyrometallurgy, including all stages of smelting, melting, and refining of high quality carbon, alloy and stainless steels. Chemical Engineering or Metallurgical degree required with a combination of both very desirable, plus four or more years of research experience.

Excellent salary and benefits are available with opportunities for creative development and professional advancement in this expanding Pittsburgh research laboratory of a leading manufacturer of specialty steels and alloys.

Send confidential resume and salary requirements to:

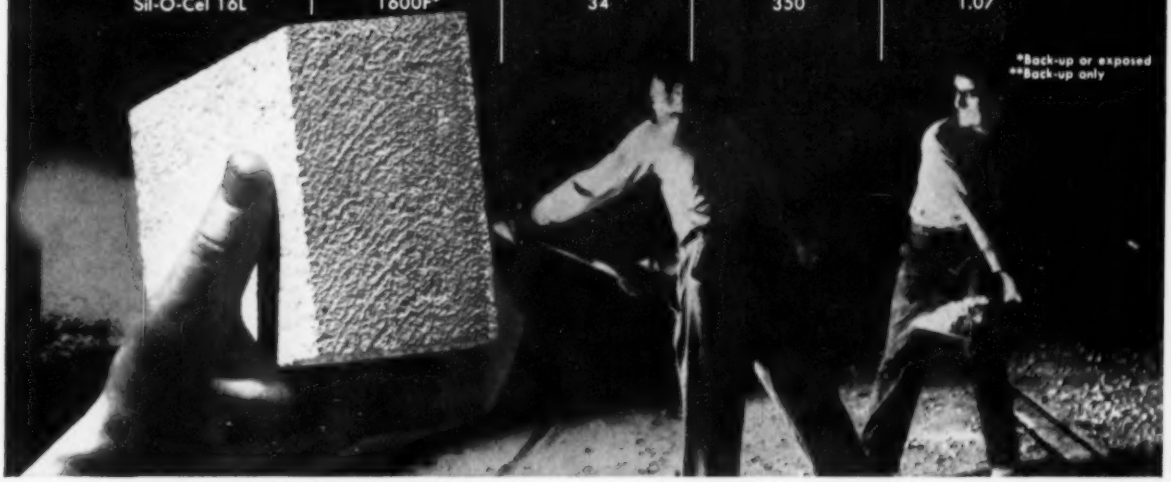
Mr. A. A. Marquer, Jr.

CRUCIBLE STEEL COMPANY OF AMERICA

P. O. Box 88 Pittsburgh 30, PA.

INSULATING FIRE BRICK	Temp. Limit	Density (lb/cu ft)	Strength (cold crushing, psi)	Conductivity (Btu in. sq ft F hr at 1000F mean temp)
JM-3000	3000F*	64	400	3.20
JM-28	2800F*	58	150	2.50
JM-26	2600F*	48	190	2.22
JM-23	2300F*	42	170	1.91
JM-20	2000F*	35	115	1.22
JM-1620	1600F* 2000F**	29	70	1.02
Sil-O-Cel Super	2500F**	40	300	1.95
Sil-O-Cel C-22	2000F**	38	700	1.88
Sil-O-Cel 16L	1600F*	34	350	1.07

*Back-up or exposed
**Back-up only



From Johns-Manville refractory research...

insulating fire brick with balanced properties for unsurpassed heat-control effectiveness

The nine types of insulating fire brick produced by Johns-Manville offer furnace builders and operators a common advantage—*balanced properties!*

The Johns-Manville insulating brick formulated for your service gives you the ideal combination of physical and thermal properties without sacrificing one for the other. This means you get unsurpassed heat-control effectiveness . . . greater economy in furnace design . . . hours saved in reaching operating temperatures!

For a good example of the value of *balanced properties*, take the proved performance of JM-3000 insulating fire brick. Formulated for 3000F temperature service, this insulating fire brick has unusual load bearing strength, high spall resistance, low shrinkage and thermal conductivity proportionate to its density.

Johns-Manville has two strategically located plants for the production of insulating brick: Lompoc, California and Zelienople, Pennsylvania. Insulating brick are available from the stocks of authorized J-M distributors in key industrial areas.

* * *

For complete information, call your nearest J-M representative. Or write for brochure IN-115A to Johns-Manville, Box 14 New York 16, N. Y. In Canada, Port Credit, Ontario.

Johns-Manville REFRACTORY AND INSULATING REFRACTORY PRODUCTS

THE INDUSTRY'S MOST COMPLETE LINE OF INSULATING FIRE BRICK

JM-3000 for temperatures to 3000F
JM-28 for temperatures to 2800F
JM-26 for temperatures to 2600F
JM-23 for temperatures to 2300F
JM-20 for temperatures to 2000F
JM-1620 for temperatures to 1600F exposed; to 2000F back-up
Sil-O-Cel Super for temperatures to 2500F, back-up
Sil-O-Cel C-22 for temperatures to 2000F, back-up
Sil-O-Cel 16L for temperatures to 1600F back-up or exposed

when you need

LITERATURE SEARCHES

TRANSLATIONS

BOOKS ON LOAN

PHOTOPRINTS

MICROFILM

why not contact . . .

The Engineering Societies Library

33 West 39th Street

New York 18, N. Y.

Please send me information pamphlet on services available, how air mail can expedite them, and their cost.

Name

Street

City

State

VACUUM MELTING

Exceptional opportunity for graduate engineer. Experience and interest in vacuum melting and furnace design are required. Experience with induction vacuum melting or consumable electrode vacuum melting a prerequisite, with experience in both very desirable.

Excellent salary and benefits are available with opportunities for creative development and professional advancement in an expanding research laboratory of a leading manufacturer of specialty steels and alloys.

Send confidential resume and salary requirements to:

Mr. A. A. Marquer, Jr.

CRUCIBLE STEEL COMPANY OF AMERICA

P. O. Box 88 Pittsburgh 30, Pa.

Personnel Service

(Continued from page 310)

five years field engineering and office sales experience covering investment castings. Salary, $8,000 to $10,000 a year. Location, New York. W4221.

RESEARCH METALLURGIST

Basic Research and Development on heat-resistant materials for application to automotive and aircraft engines. Excellent facilities and opportunity for investigating the physical metallurgy, deformation, and fracture behavior of high-temperature alloys.

Write or phone

W. A. Johnson

Associate Director of Research

THOMPSON PRODUCTS, INC.

23555 Euclid Avenue

Cleveland 17, Ohio

METALLURGISTS and METALLURGICAL ENGINEERS

Opportunities exist for both recent graduates and those with several years' experience in research, development, failure analysis, heat treating, corrosion testing, metallography, welding and general applications of metallurgy. Fully equipped, modern laboratory in Southern Ohio. Send reply with resume and salary information to:

Employment Department XX

GOODYEAR ATOMIC CORPORATION

P. O. Box 628

Portsmouth, Ohio

Production Engineer, 30 to 40, with mechanical or metallurgical engineering training and at least five years supervisory operating experience in sheet rolling mill. Salary, $9,000 to $10,000 a year. Location, West Virginia. W4218.

Sales Engineer, young, with metallurgical training and knowledge of welding, to sell hard-facing alloys and metallizing powders in eastern states. Must have car. Salary, $5000 to $6000 a year plus commission and expenses. W4215.

Test Engineers. a) *Ore Test Engineer,* graduate metallurgist or chemist, to lay out test procedure in laboratory. Should have strong managerial ability. Salary, $8000 to $9000 a year; b) *Ore Test Engineer,* graduate metallurgist or chemist, to run ore analysis and extractive metallurgical tests. Will accept recent graduate. Salary, $4800 to $5400 a year. Company will pay placement fees. Location, Denver. W4208.

Sales Engineer, graduate with metallurgical or chemical engineering degrees, to contact, on assignment, established and new accounts to determine equipment requirements in the mineral processing industry. Previous sales experience not essential. Travel, 25 pct. Base salary, $6000 a year plus commission. Company will pay placement fee. Headquarters, New York and Denver. W4207.

MINING AND SMELTING ENGINEERS. To men experienced in designing facilities in nickel or allied fields, permanent responsible positions are available with long established firm. Headquarters Detroit and Windsor, Ontario. Please send full resume to:

Box 6 JM AIME
29 West 39th St. New York 18

METALLURGICAL ENGINEERING teachers at San Francisco Bay Area College. Expanding program; $4 million building addition now being planned; excellent part-time industrial and graduate work opportunities; excellent salary scale. Write to Head, Engineering Department, San Jose State College, San Jose 14, California.

Manufacturer of high-temperature alloys requires a Technical Director at staff level. The man we seek is a mature metallurgist with a proven record as an administrator of research both basic and applied. He must be interested in the challenge offered by a growing concern which will provide generous support both for the building up of an outstanding research department and for his own financial security. Salary open; executive bonus. Replies held in strictest confidence. Send resume and salary requirements to:

Box 4 JM AIME
29 West 39th St.
New York 18

Introducing USS TENELON*

Cr-Mn-N

—austenitic stainless steel without nickel

EVER SINCE WORLD WAR II, American steelmen have been painstakingly searching for high-efficiency steels using as little nickel and other critical materials as possible. This is a decidedly worthwhile objective, especially so in view of the fact that no one knows when a national emergency will again confront us.

It now appears that this desirable objective has been attained in the field of austenitic stainless steels. For in USS TENELON—developed by United States Steel—we have a remarkable new steel which, if it lives up to its early promises, should be a potent aid in helping this country conserve the supply of critical nickel. TENELON *stainless steel requires no nickel whatsoever.*

Aptly called a stainless steel milestone, nickel-free USS TENELON is a *completely austenitic* stainless which in the annealed condition has higher mechanical properties—higher yield strength and higher tensile strength—at both room and elevated temperatures than many of the conventional nickel-bearing austenitic grades.

With the development of USS TENELON, a new term has been introduced in the vocabulary of steel metallurgy: Cr-Mn-N steel—an unfamiliar abbreviation that clearly reveals the secret of USS TENELON. In this steel, manganese and nitrogen replace nickel inasmuch as they exert similar beneficial effects on the microstructure and mechanical properties. Here is a typical analysis of USS TENELON:

C	Mn	P	S	Si	Ni	Cr	N
.10 Max	14.50	.045 Max	.03 Max	1.00 Max	—	17.00	.40

Notice that, to enhance corrosion resistance, the carbon content has been kept low and the chromium level maintained equal to that of Type 301 stainless steel. The combination of Mn and N at the indicated levels produces an austenitic structure over a wide temperature range. Moreover, it assures the good hot workability necessary for commercial production.

At elevated temperatures, TENELON stainless steel has tensile and creep rupture properties superior to those of 18Cr-8Ni stainless steel and about equal to those of 18-8 Cb and 18-8Mo, all three of which require large amounts of critical elements.

Exposure tests now underway indicate that in rural, industrial and marine atmospheres, the corrosion resistance of USS TENELON in all these environments is comparable to Type 302 (18Cr-8Ni) stainless. Extensive laboratory tests show that in milder acids—lactic, phosphoric and acetic—the corrosion losses of USS TENELON are about equal to those of Types 301, 302, and 201 stainless steels. In stronger acids such as 5% sulphuric and boiling 5% nitric, this new stainless, though inferior to these grades, is equal to or better than Type 430.

USS TENELON is new and, although a number of commercial heats of this steel have been produced, the testing program is still incomplete. However, on the basis of tests made to date and others nearing completion, TENELON is emerging as a stainless steel eminently suited for rail cars, automotive vans and tank-trailers, liquid fertilizer tanks, and for various military and other applications where it can be used in its annealed as well as cold rolled condition to save structural weight and conserve nickel.

The trademark name, TENELON, is derived from the steel's *high tensile* strength and unusual *elongation* (indicative of very great ductility). In short, this steel is named for the very properties that should lead to its use in place of many stainless steels that, to achieve comparable properties, depend on relatively large amounts of critical alloy elements.

• • •

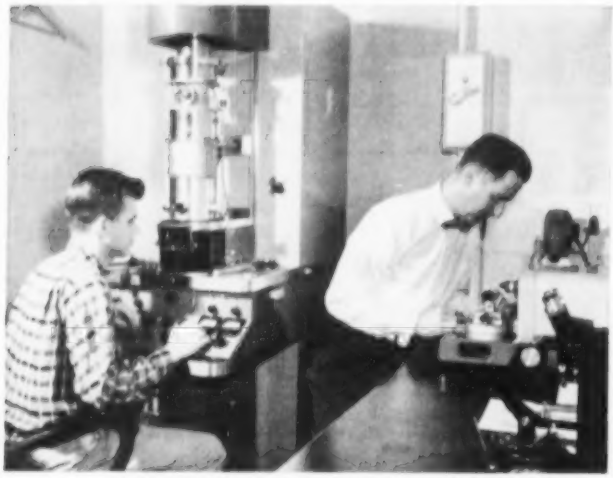
The development of TENELON is typical of the unremitting efforts of United States Steel to continually produce better steels that not only more effectively meet the needs of American Industry but will benefit the Nation as a whole. United States Steel Corporation, 525 William Penn Place, Pittsburgh 30, Pa.

**Trademarks*

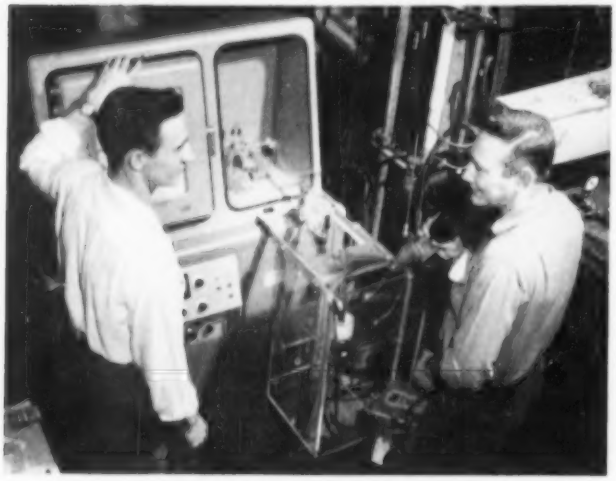
USS

UNITED STATES STEEL

Dr. Benjamin Lustman, Manager of Pressurized Water Reactor Metallurgy, and technician K. Marsh are testing the mechanical properties of zirconium brazing alloys.



Dr. M. W. Burkart, Fellow Engineer, and Mr. P. Schnizler, technician, are examining the fracture surfaces of UO_2.



Mr. W. A. Bostrom, Senior Engineer, and technician W. Bowen measure gas transport in metals using mass spectrometric analysis.

METALLURGISTS

can you identify these tests?

If you are interested in exceptional career opportunities, the expanding nuclear power industry offers you a creative challenge.

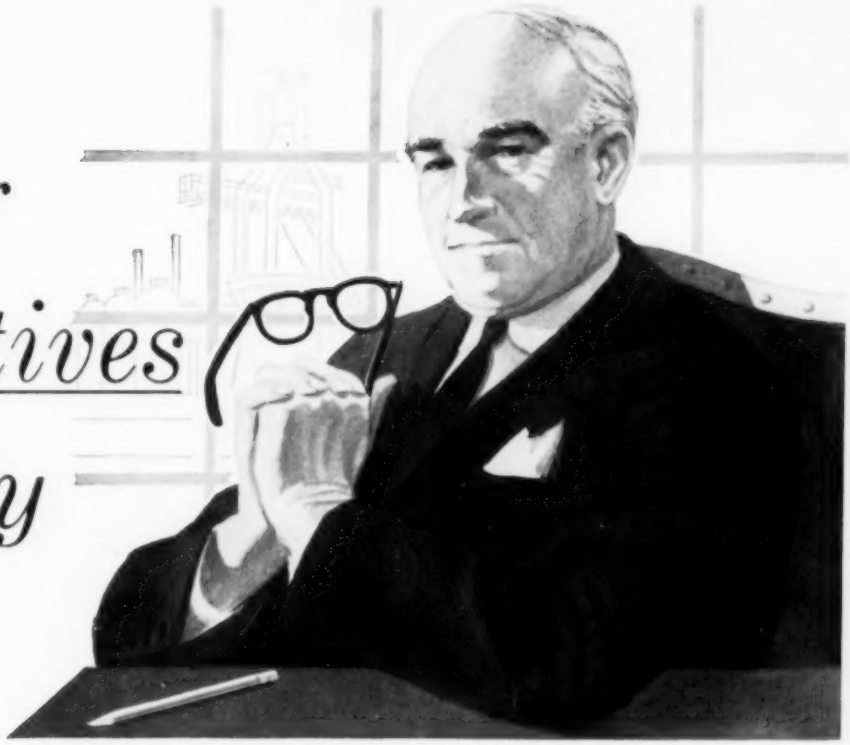
Metallurgists engaged in alloy development work are pictured in well-equipped Westinghouse Bettis Plant laboratories. They are performing tests which involve kinetics and mechanisms of corrosion and oxidation, mechanical properties, and solid state transformations. A few other examples of work, not shown, include x-ray diffraction analysis, physical chemistry of molten metals, phase diagram determination, and irradiation effects in metals. These represent some of the experiments necessary to develop the materials for fuel elements and vessel structure which will be used for nuclear reactors and cores. Designed and developed by Bettis scientists and engineers, these reactors will power nuclear submarines and surface ships as well as the nation's first full-scale commercial nuclear power station.

We welcome inquiries from metallurgists who are interested in joining outstanding scientists for a career in nuclear power. Please address resumes to: Mr. A. M. Johnston, Dept. A-131, P.O. Box 1468, Pittsburgh 30, Pennsylvania.

BETTIS PLANT

Westinghouse

For Executives Only



- Interested in producing low-carbon steels
- Decreasing production man-hours
- Increasing shippable yields

Man-hours of production cost and shippable yields now afford the steel producer just about the only opportunity for improvement to meet price and quality competition.

The addition of but small quantities of MCA rare earth materials frequently results in valuable savings in surface preparation costs and increased shippable yields, both of which have been demonstrated in production runs. Plate steels, deep-drawing sheet steels, low-carbon steels, silicon and stainless steels, and steels demanding transverse properties are among those especially susceptible to improvement with rare earths.

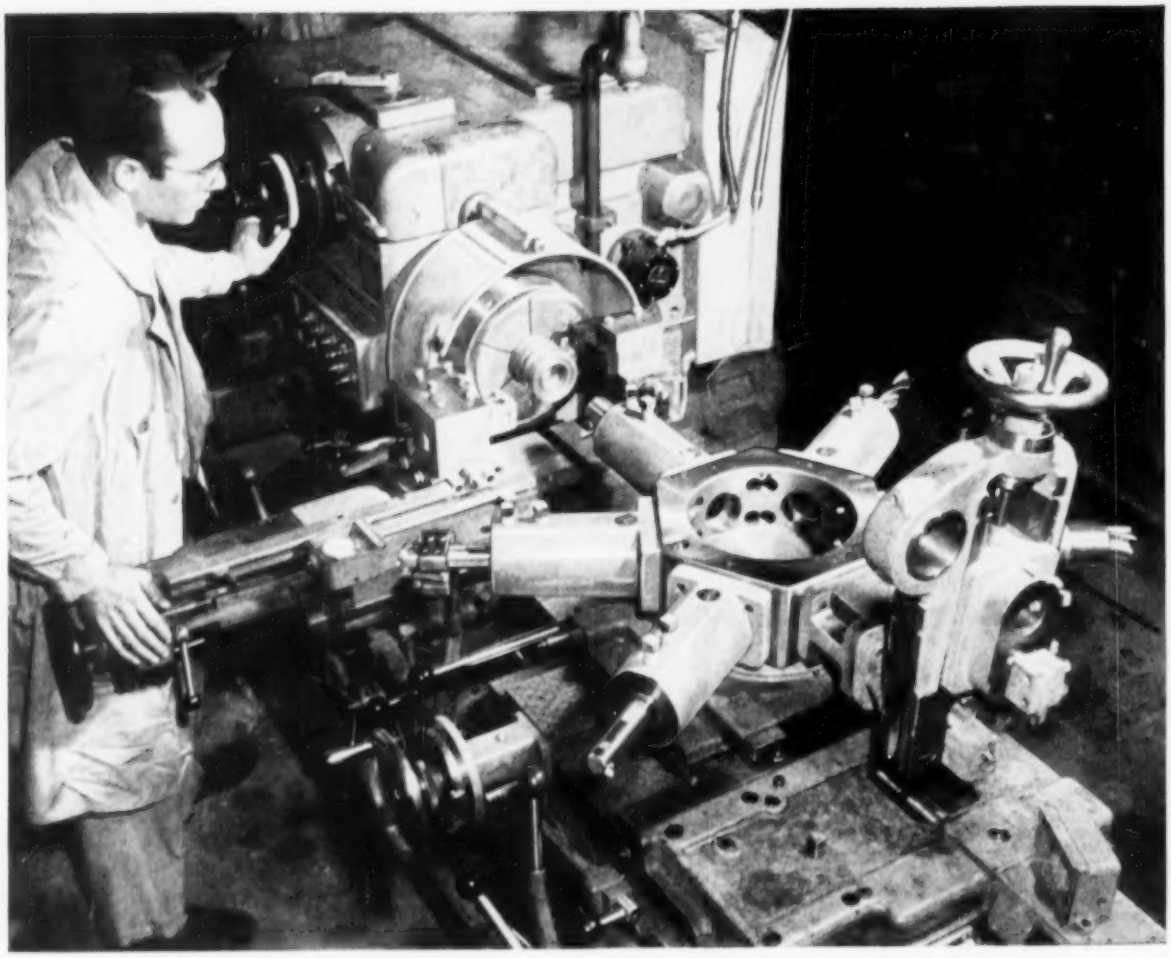
The substantiated proof of rare earths in steel-making economy and MCA's technical knowledge are unsurpassed. Write or call today for details.

MOLYBDENUM

Grant Building CORPORATION OF AMERICA **Pittsburgh 19, Pa.**

Offices: Pittsburgh, Chicago, Los Angeles, New York, San Francisco
Sales Representatives: Brumley-Donaldson Co., Los Angeles, San Francisco
Subsidiary: Cleveland Tungsten, Inc., Cleveland
Plants: Washington, Pa., York, Pa.

MCA



New Gisholt 30 H.P. Turret Lathe features a compact, integrated headstock, bedframe design. Nickel alloyed components help keep the 12-speed unit running smoothly . . . dependably at top performance. Produced by Gisholt Machine Co., Madison, Wisconsin.

Gisholt depends on nickel alloy steels for highly stressed parts in new saddle-type turret lathes

In Chuck Screws—carburized type 3312 nickel chromium steels with wear resistance plus a tough case to prevent thread chipping, and a strong core to carry heavy torsional loads.

In Certain Headstock Gears—type 4620 Ni-Mo case-hardened to provide wear resistance and strength with a minimum of distortion during heat-treatment.

In Drive Pinions for Hexagon Turret Saddles—where 4340 Ni-Cr-Mo steel quenched and tempered to 40-45 Rc has proved its uniformity and reliability through years of service.

Three problem parts! Three practical solutions for Gisholt! All proved . . . with nickel alloy steels. What about critical metal parts in *your* products?

Chances are, too, that solutions to the problems they present lie in the outstanding combinations of properties available from steels containing nickel. Why not take advantage of Inco's available knowledge of the capabilities of nickel steels. Send us the details of your problem, and we will be glad to suggest possible solutions.

INCO **THE INTERNATIONAL NICKEL COMPANY, INC.** 67 Wall Street New York 5, N.Y.

Cobalt . . . U. S. Production

The 1956 U. S. cobalt production is estimated to have been some 2500 tons, while metal imports amounted to 6000 tons. From domestic ores, output was some 1700 tons of metal. The Blackbird mine of Howe Sound Co., the largest producing mine in the Western Hemisphere which supplies the Garfield refinery of Calera Mining Co., was producing close to its 1500-ton capacity. At the Garfield plant, research is underway on a process for producing high purity electrolytic cobalt. For a description of the Garfield plant turn to p. 343.

Cobalt . . . U. S. Consumption

With 1956 U. S. cobalt consumption estimated at 8500 tons, some 3500 tons probably went to the strategic stockpile. Of the remaining 5000 tons some 50 pct was for high temperature alloys, 30 pct for alloys for magnets, and 20 pct for pigments, electroplating, etc.

Cobalt . . . In the Belgian Congo

The Belgian Congo accounts for some two thirds of the cobalt output of the noncommunist world and is the largest supplier to the U. S. market. By far the largest producer in the Congo is the Union Minière du Haut Katanga, which produced some 10,000 tons in 1956, an increase of 500 tons over 1955.

New Developments in Magnets

High-cobalt iron alloys, the traditional magnet material, are meeting increasing competition from alternatives. One such group are the ferrites, a hard ceramic material artificially produced by the fusion of iron oxide with oxides of other metals. While poor electrical conductors, ferrites exhibit a high degree of permeability to electromagnetic waves. Another material, the compound MnBi, is prepared by grinding manganese and bismuth together in a helium atmosphere and heating to 520° F. The resulting MnBi is reground and imbedded in a plastic matrix, oriented in a powerful magnetic field. Each particle is itself a tiny magnet, thus the material has a particularly high resistance to demagnetization.

Cobalt Research Group at Battelle

With increasing competition from substitutes in magnets and expanding cobalt output, world production is generally conceded to exceed peace time commercial requirements. To encourage cobalt research and produce technical and economic information for users, a Cobalt Information Center was recently established at Battelle Memorial Institute in Columbus, Ohio.

Manganese from Low Grade Ores

With the U. S. almost completely dependent on imports of manganese ores, considerable interest has centered on the development of economic processes for producing ferromanganese from low grade domestic ores. . . . General Services Administration has announced the award of a contract to U. S. Manganese Corp. to pilot a process using Colorado rhodonite as a raw material. The new firm was formed by Vitro Corp., Sheer-Korman Assoc., and Great Divide Mining & Milling Corp. The process consists of compressing a flotation concentrate with coal dust into an electrode which is used in a high intensity arc process. . . Strategic-Udy Metallurgical and Chemcial Processes Ltd. has commenced operation of a $2 million prototype ferromanganese plant at Niagara Falls, Ont., Canada to process ore averaging 13 pct Mn and 19 pct Fe. For a description of the process, see p. 340.

Order Your Copy---

1956 BLAST FURNACE PROCEEDINGS VOL. 15

The Proceedings of the 1956 Conference of the Blast Furnace, Coke Oven, and Raw Materials Committee, Iron and Steel Division, AIME, can be purchased by those unable to attend the Conference held in Cincinnati, April 9-11, 1956.

Use the convenient order form below.

Several volumes of recent Conferences are still in stock, and can also be purchased.

These valuable papers were presented at the 1956 Conference:

Sizing and Sintering of Ores

Design and Operation of No. 3 Sinter Strand at Jones and Laughlin's Benson Mines. By R. G. Fleck and F. M. Hamilton.

The Lurgi Sintering Plant of the Steel Company of Canada. By T. W. W. Trumper.

Ore Preparation Plant of The Steel Company of Wales Limited—Design, Operation, and Effect on Blast Furnace Performance. By K. C. Sharp and H. R. Tufnell.

Weirton's New Eight Foot Wide Iron Ore Sintering Plant. By Julius H. Strassburger.

Blast Furnace Operations

Operating Experiences with High Beneficiated Burdens. By D. Joyce, W. P. Dowhanyuk, and B. Marsden.

The New High-Grade Iron Ores and Agglomerates and Their Effect on Coke Rates. By John Griffen.

Burdening a Blast Furnace for Minimum Costs. By David R. Bailey.

Comparison of Blast Furnace Penetration with Model Studies. By J. B. Wagstaff and W. H. Holman.

Desulphurization of Hot Metal

Application of Theoretical Principles to Desulphurization in Iron and Steel Making. By John F. Elliott.

Desulphurization with Calcium Cyanamid in Hot-Metal Ladles. By G. G. Hatch, G. E. Wagner, and M. Trottier.

Desulphurization of Molten Iron. By J. N. Hornak and E. J. Whittenberger.

Desulphurization of Blast Furnace Iron with Injected Calcium Carbide. By Daniel E. Watkins and J. R. McFarland.

Coal and Coke

Pilot Scale Coke Ovens—Development and Operation. By R. Tracy Eddinger and John Mitchell.

New Pressure Recording 18 Inch Test Oven. By R. P. Atkinson.

Study of Pressure Relationships in Commercial Coke Ovens. By D. C. Coleman and P. J. Farley.

Low Fuel Rates Obtained with Three-Foot Blast Furnace Using Prepared Ores and Coke-Anthracite Mixtures. By Russell C. Buehl and Miles B. Royer.

Research and Development on Sintering

Reaction Zones in the Iron Ore Sintering Process (JOURNAL OF METALS Award Paper). By R. D. Burlingame, Gust Bitsianes, and T. L. Joseph.

Sintering Investigations Using Factorial Design Experiments. By T. L. Myron, C. J. Davis, and R. L. Franklin.

Methods for Increasing Production Rate of Flue-Dust Sinter. By E. E. Rudolphy and E. J. Whittenberger.

Sintering Iron Ores and Concentrates at Extaca. By Robert L. Bennett, Robert E. Hagen, and Morris V. Mielke.

AIME, 29 W. 39th St., New York 18, N. Y.

☐ Please send me a copy of the *1956 Blast Furnace Proceedings*. I also wish to purchase Proceedings for the following Conferences:

- ☐ 1955 (Vol. 14)
- ☐ 1954 (Vol. 13)
- ☐ 1953 (Vol. 12)
- ☐ 1952 (Vol. 11)
- ☐ 1951 (Vol. 10)

Enclosed is Check ☐ Money Order ☐ for $

(AIME members may be billed.)

Name

Address

City and Zone State

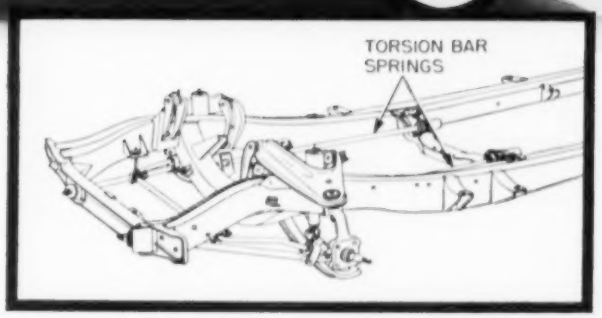
Nonmember Foreign Order, Add 50c for Mailing

Price: $10.00

... AIME Members: $7.00 ...

XRD-5
DIFFRACTION UNIT

a proved General Electric X-Ray product to make your products better



How Chrysler used x-ray diffraction in perfecting new Torsion-Aire Ride

Frame and front-end suspension for the 1957 Plymouth. G-E X-Ray Diffraction Unit played an important part in metallurgical testing of torsion bar materials.

ONE of industry's most thorough engineering development projects is found in the dramatic new Torsion-Aire suspension system, a key feature of *THE FORWARD LOOK* for '57. But Chrysler faced a problem — how to best produce and heat-treat torsion rods.

Chrysler's Research Section studied the problem with their G-E X-Ray Diffraction Unit. Here's how it was done. X-ray measurements of residual stress were made to accumulate basic information. Such study clearly established the residual stress distribution *capable of maximum fatigue life expectancy.*

For Chrysler's many customers this means dependable performance of a suspension system that's designed to deliver "sports-car" maneuverability and "limousine" boulevard ride.

General Electric's x-ray diffraction equipment offers *you* fast, accurate qualitative and quantitative analysis of both solids and liquids. A full range of accessories lets you make the most of advantages offered by both the diffractometer and x-ray emission spectrometer . . . yet, design is such that you can start with minimum equipment, add features as your needs grow.

For complete details, consult your G-E x-ray representative. Or, write X-Ray Department, General Electric Company, Milwaukee 1, Wisconsin, for Pub. AY-34.

XRD-5D/F — latest model General Electric X-Ray Diffraction Unit. This instrument in your own laboratory will provide answers to tough problems in metallurgy or chemistry.

Progress Is Our Most Important Product

GENERAL ELECTRIC

Available ---

Order Now -

A NEW LOOK AT THE NATURE OF THE OPEN-HEARTH PROCESS

by

B. M. LARSEN
Research Supervisor
United States Steel Corporation
Monroeville, Pennsylvania

NATIONAL OPEN HEARTH STEEL COMMITTEE
IRON AND STEEL DIVISION

$3.00

AIME Members: $2.00

American Institute of Mining, Metallurgical, and Petroleum Engineers
29 West 39th Street
New York 18, N.Y.

TABLE OF CONT

PREFACE
INTRODUCTION
Need for a Working Theory of the Process
I. FLOW OF HEAT INTO THE BATH
1. Mean Net Heat Flow over Whole Heat
2. Flow Rate from Temperature Rise in
3. Heat Flow Potential between Roof a
4. Total Available Heat Supply to the
5. Mechanism of Slag-Metal Heat Flo
6. Implications of This Theory of H
II. GAS-LIQUID DIFFUSION AND CARB
1. Mechanism and Rate of Met
2. Origin of CO Bubbles in
3. Sampling for Dissolved
4. Basis for Diffusion Rat
5. Kinetics of Carbon Ox
6. Interpretation of Obs
III. SOME CHARACTERIST
1. Comparison of Bessemer,
2. Some Puzzles in Open Hearth
3. Distribution of Flame in Furnace Sp
4. Examples of Leakage and Excess Air—E
5. Factors Involved in Regenerator Efficiency
6. Regenerator Efficiency and Cold Air Leakage Distrib
7. Examples of High and Low Regenerator Efficiency
8. Excess Air and Efficiency of Regeneration Related to Air Distr
IV. AIR OXIDATION AND NET HEAT REQUIREMENT OF THE BATH
1. Oxygen Balances
2. Mechanism of Air Oxidation
3. Iron Burning and Scrap Melting
4. Oxygen Absorbed from Air—Effects on Net Heat to Bath
5. Air Oxidation and Melt Carbon
6. Excess Air and Combustion of Bad Gases
7. Examples from Commercial Practices
8. Summary of Relationships to Production Rate
9. A Note on Furnace Design
V. AVENUES FOR STUDY OR DEVELOPMENT
REFERENCES
37
38

AIME, 29 W. 39th St., New York 18, N. Y.
Please send me a copy: **A New Look at the Nature of the Open-Hearth Process**

Enclosed is Check ☐; Money Order ☐ for $
(AIME members may be billed.)

Name

Address

City and Zone State

Nonmember Foreign Order, Add 50¢ for Mailing.

USE the Handy Order Form ---

BOOKS

ORDER YOUR BOOKS THROUGH AIME—Address Irene K. Sharp, Book Dept. AIME members given 10 pct discount whenever possible. Please order Government publications direct from the agency concerned.

Stress Corrosion Cracking and Embrittlement, ed. by W. D. Robertson, *John Wiley & Sons Inc.*, 200 pp., $7.50, 1956.—This book presents the material set forth at the Symposium on Stress Corrosion Cracking, arranged by the Corrosion Division of the Electrochemical Society in 1954. Among the subjects discussed are grain boundaries, boundary adsorption, and stress corrosion cracking in alloys and steels.

Symposium on High-Purity Water Corrosion, Special Technical Pub. No. 179, *American Society for Testing Materials*, 56 pp., $1.75, 1956.—The five papers contained herein were given at a symposium sponsored by Committee D-19, and deal with the phenomena associated with high-purity water and its corrosive effects under various conditions. Bibliographies and illustrations accompany the text.

Progress in Metal Physics, Vol. 6, ed. by B. Chalmers and R. King, *Pergamon Press Ltd.*, 339 pp., $12.00, 1956.—This volume, in a series providing reviews of new work in the field of metal physics, contains papers on the effect of hydrostatic pressure on electrical resistivity, filamentary growth, the austenite to pearlite reaction, creep in metals, the mechanism of evaporation, and mosaic structure.

Symposium on Impact Testing, Special Technical Pub. No. 176, *American Society for Testing Materials*, 170 pp., $3.50, 1956.—This is a collection of papers sponsored by Committee E-1 on Methods of Testing. Discussed are impact and shock tests for parts, components, and complete structures. Attention is given to impact tubes and environmental conditions. Illustrative and bibliographical materials are included.

Please Order These Publications from the Publishers

Tinplate Handbook, by W. E. Hoare, *Tin Research Institute Inc.*, 492 West Sixth Ave., Columbus 1, Ohio, 44 pp., free, 1956.—This booklet is the 3rd edition of a handbook of facts about tinplate for buyers and users. It contains statistical data about tinplate production, as well as information on its manufacture, grades, qualities, testing, and applications. A foreign language glossary of tinplate terms is included.

KINNEY high capacity pumping system shown at left.

This 500 lb. melting and casting furnace, remotely controlled from a graphic panel, can be readily converted to semi-continuous operation by addition of Vacuum locks.

"The outfit with the 'know how' has the answers"... and this is doubly true in Vacuum technology! KINNEY High Vacuum Pumps provided the answers "away back when" and you can practically chart the significant advances in Vacuum processing by the developments contributed to the art by KINNEY engineering.

The KINNEY oil sealed rotating plunger Pump, producing pressures down to 0.2 micron, continues to be the outstanding Pump of its kind in the world. The KINNEY Mechanical Booster Pump, introduced but four years ago, is contributing important advantages in securing clean, dry Vacuum at even lower pressures.

Now KINNEY offers the metallurgist new tools for production and research...complete High Vacuum Systems – Evaporators, Furnaces, Drying Ovens and Packaged Pumping Systems. And for the Metals industry – Complete High Vacuum Systems for Melting, Degassing, Casting, Refining and Heat Treatment.

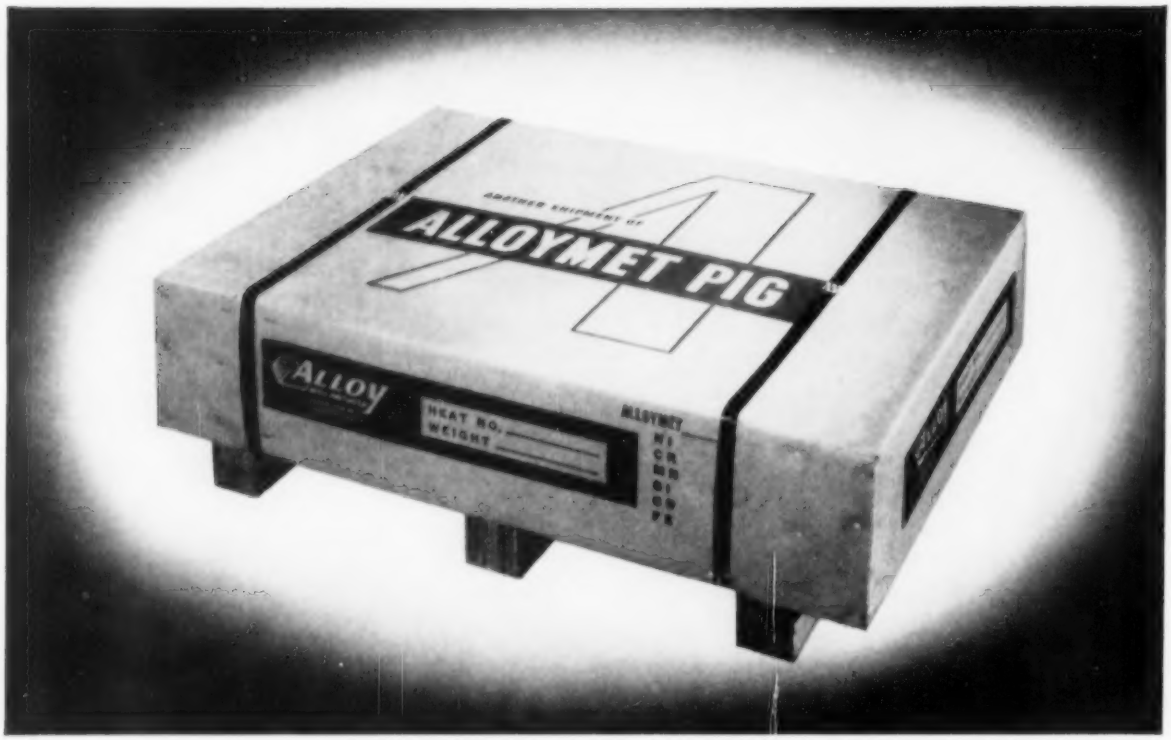
Yes, "for new developments in Vacuum Metallurgical Equipment" get the answers – *based on experience* – from KINNEY.

WRITE: for Catalog No. 425, fully describing KINNEY High Vacuum Pumps, or for detailed information on your specific problem.

KINNEY MFG. DIVISION
THE NEW YORK AIR BRAKE COMPANY
3562C WASHINGTON STREET · BOSTON 30 · MASS

Kindly send me catalog No. 425 ☐
Also send further information on your complete Vacuum equipment ☐

Name_____
Company_____
Address_____
City_____ Zone____ State_____



NEW "BOX LUNCH" of NICKEL ALLOY

speeds feeding of electric furnaces

26 nickel alloy pigs, each weighing about 50 pounds, travel inside this new palletized package. Weight and certified analysis are in plain view at all times. All fiberboard, it can go into the electric furnace "as is." It weighs only ¼ as much as a wooden pallet. Saves on transportation costs. Discourages pilferage. Speeds handling.

Users are already enthusiastic about this new nickel alloy package. Like the quality product it contains, it serves as a further example of the exacting care Alloy Metal Products, Inc., exercises in every phase of the production of alloy metals.

If you are still using scrap for your alloy requirements, ask us about Alloymet pig of certified analysis.

ALLOY
METAL PRODUCTS, Inc.
PHONE 6-2561 • TELETYPE DV 588
(FORMERLY A DIVISION OF **ALTER COMPANY**)
ROCKINGHAM ROAD
DAVENPORT, IOWA

World's largest producer of secondary nickel alloys of certified analysis

EDITORIAL

Engineering Societies Library

SOON after the AIME was founded it began to collect books at its headquarters. This was also true of the American Society of Civil Engineers, the American Society of Mechanical Engineers, and the American Institute of Electrical Engineers, who later combined their libraries with that of AIME to form the Engineering Societies Library. None of these collections in their early days could truly be called libraries, for they were largely unindexed and uncatalogued; yet even so, the collections were useful and the Societies were proud of them. A history of one of the Societies reports several moves in its early years to acquire more space for its staff and library. One move is recorded as being particularly satisfying, for the premises had improved gas lighting where its members could read at night!

About the turn of the century there was much discussion of a union home for the engineering societies but, despite the discussions, little was done for many years. In 1903, Schuyler Skaats Wheeler, a member of the AIEE, became the possessor of a remarkable collection of electrical books which had belonged to Latimer Clark, an English engineer. Mr. Wheeler said, in presenting the collection to the AIEE, that it was his intention to make it the custodian of the most complete electrical library in the world as well as to stimulate such interest that the Institute might in time own a permanent home in New York. This fine collection of electrical books, and the libraries of the other Founder Engineering Societies were called to the attention of Andrew Carnegie and undoubtedly they were important factors in arousing his interest and help in securing the present building.

How It Began and Grew

In 1907, three of the present Founder Engineering Societies moved their offices into the building at 29 W. 39th St. and placed their separate collections of books adjacent to each other in the reading room on the 13th floor of the building. By 1913 the three Societies agreed to merge their libraries under the direction of a trained librarian and a single library board. A few years later the ASChE moved into the building and its library became a part of the Engineering Societies Library.

The Engineering Societies Library, the library of the Four Founder Societies, is a department of the United Engineering Trustees Inc. The Library Board is composed of representatives of the Four Founder Societies and of UET. Prior to merging the libraries, some of the Societies were spending well over $1 per member annually for library operations, not including light or heat. Since the libraries have been combined, the cost is about one half of this. The Four Founder Societies' contribution to the Library amounts to about $80,000 this year. Income from services rendered by the Library is nearly $50,000.

Library Contents

The relatively unorganized separate collections of more than 40 years ago have been combined, organized, and catalogued. Duplication has been eliminated and much material received years ago as gifts, but of little value to engineers, has been discarded. Through the direction of the Founder Societies' members who have served on the Library Board, and through the work of many staff members, the Engineering Societies Library has become outstanding in the fields of the Founder Societies—civil, electrical, mechanical, mining, metallurgical, and petroleum engineering. The Library contains some 173,000 volumes covering all branches of engineering, primarily on the level of graduate and practicing engineers. Over 1400 periodicals are currently received from all parts of the world.

Through cooperation with the Engineering Index, important engineering books and articles in periodicals received by the Library are indexed in the daily card service and annual volumes of the Engineering Index. Through this—the world's most extensive published index to engineering literature—engineers have a key to the excellent collection of the Engineering Societies Library.

Library Services

The Engineering Societies Library has developed services that make it useful to those who cannot visit the Library as well as to those who can. Its staff prepares reviews of hundreds of important engineering books each year. These reviews, published in the journals of the Founder Societies and of other organizations, make it easy for engineers to learn about new engineering books of interest to them. These and other books in the Engineering Societies Library may be borrowed by members of the Founder Societies in the U. S. and Canada. Each year thousands of engineers and organizations use the Library's literature searching and translation services and its photoprint and microfilm copying services that are available to anyone anywhere without membership restriction. Other thousands use the public reading room of the Library.

Visitors to the reading room reached an all time high during the depression years of the 1930's, but since then the number of those served outside the Library has continually increased and such service now exceeds visitor use of the Engineering Societies Library. This is a desirable trend, as it widens the usefulness of the Library; however, it adds greatly to the work of the Library, for a request answered by mail takes much more time than one answered in the reading room where the inquirer usually does most of the work of finding the information wanted.

The Library Today

The Engineering Societies Library is a busy information center. Last year 75,000 photoprints were made and sent to engineers everywhere. Microfilm is particularly favored by those in foreign countries who order copies of material in this Library. Hundreds of thousands of words have been translated from a dozen different languages into English in each recent year.

Literature searches made on specific order help engineers improve the products of industry. They enable researchers to start from where previous work has stopped, and in many other ways save the time and expense of engineering work. All literature search work is kept confidential. In addition, the Library prepares bioliographies which are of general interest and are available for purchase by anyone.

A free information folder about the Library and its services, and a list of available bibliographies are available on request to the Engineering Societies Library, 29 W. 39th St., New York 18, N. Y.

—Ralph H. Phelps

MEMO
I wonder if a longer electrode would prove more economical?
MEMO
Let's call Great Lakes Carbon--they've always been helpful, and they're good people to work with!

ELECTRODE GLC DIVISION

GREAT LAKES CARBON CORPORATION
18 EAST 48TH STREET, NEW YORK 17, N.Y. · OFFICES IN PRINCIPAL CITIES

1957 POWDER METALLURGY SYMPOSIUM

THE symposium on powder metallurgy which is published on the following pages was arranged by the Powder Metallurgy Committee of the Institute of Metals Division and presented at the AIME Annual Meeting in New Orleans on Feb. 28, 1957.

One of the principal purposes of this symposium was to acquaint engineers in the southwestern part of the country with the techniques of powder metallurgy. The subjects of the first two papers were, therefore, chosen because of their particular interest to engineers in the aircraft and petroleum industries. Filters made from metal powders are widely used both in airplanes and engines. For drilling wells, the use of cemented carbides and impregnated diamond drilling bits, important products of the powder metallurgy industry, need hardly be emphasized.

These two individual papers are followed by a panel discussion on high strength structural parts. Fabricating structural parts from metal powders lifted powder metallurgy beyond the limits of a technique used only for rather specialized applications, and put it squarely into competition with other, more conventional methods of fabricating machine parts, such as machined castings or steel bar stock, diecasting, forging, etc. Powder metallurgy as a technique for making such parts was, at first, limited to applications where only moderate mechanical properties, comparable to those of a medium grade of cast iron, were required. Raising the level of mechanical properties of these parts by techniques which have been recently developed has opened up large numbers of potential new applications to the powder metallurgy technique. A mere beginning has been made in actually exploiting these applications. The panel discussion was therefore designed to acquaint engineers with the new possibilities in powder metallurgy. —*F. V. Lenel*

powder metallurgy symposium

Metallic Filters By Powder Metallurgy

It was during the late 1930's that sintered bronze filters were first produced because of their strength, corrosion resistance, and efficiency in filtering fine particles from a stream of liquid or gas. Ten years ago stainless steel filters were first produced by powder metallurgy, and only two years ago metallic fiber filters were put on the market. Today powder metallurgy promises many interesting new developments in this field.

by John Haertlein

THE process of separating solids from a fluid, either liquid or gas, can be accomplished in many ways. One of these is filtration. Various paper and resin filters have been used for years to clarify liquids. But it has always been recognized that these filters have many disadvantages—poor strength, little heat resistance, adsorption of additives from the fluids, and lack of resistance to chemical attack. In addition, their pressure drop characteristics are generally quite poor.

Metal screens have long been used to remove particles coarser than 44 μ from a fluid, since they have strength, corrosion resistance, and many other desirable properties. For finer particles, no suitable materials were available until in the late 1930's, when the combined efforts of Metals Disintegrating Co. and Moraine Products Div. of General Motors Corp. produced the sintered bronze filters, which are now the most popular metallic filters available. Approximately ten years ago, stainless steel filters were first produced commercially by powder metallurgy methods. The most recent innovation in this field, the metallic fiber filters, has come out commercially only in the past two years.

It is difficult to make an overall comparison of the various materials available for filtering purposes because each application has specific requirements influencing the workability of any given filter media. However, Table I presents a rough comparison of the advantages of various materials now available for clarification purposes.

JOHN HAERTLEIN is Research Metallurgist, Metals Disintegrating Co., Elizabeth, N. J. This paper was presented in the Symposium on Powder Metallurgy of the AIME 1957 Annual Meeting.

The sintered bronze filters were designed to take advantage of the most favorable properties of both the metallic screens and paper and felt filters. Screens, being made of woven metal cloth, have uniformly sized pores, but their passages are straight, and various types of irregularly shaped particles can pass through with ease. Paper and felt filters, made by the random arrangement of variously sized fibers as they are laid down on a screen from a suspension, have layers of fibers resulting in irregularly shaped pores. As a result, a contaminant particle trying to penetrate one of these filters will be forced to follow a tortuous path from entrance to exit and, therefore, will be presented with many opportunities to get lodged in cracks and crevices of the filter material. This mechanism will remove many fines, but the non-uniformity of the starting material will produce paths where relatively large particles can slip through with ease. Therefore, the foreign material in the filtrate from paper filters will have a considerably greater particle size range for paper-type filters than for metallic filters.

Bronze filters explained by geometry of spheres.

Sintered bronze filters have the uniformly sized pores of the metallic screens, and in addition they have the depth of filtration of the paper-type filters. To understand this a little better, let us take a brief look at the geometry of spherical packing. Spheres can either arrange themselves in the form of squares, where each particle is touched by four others in the same plane, or the particles can arrange themselves

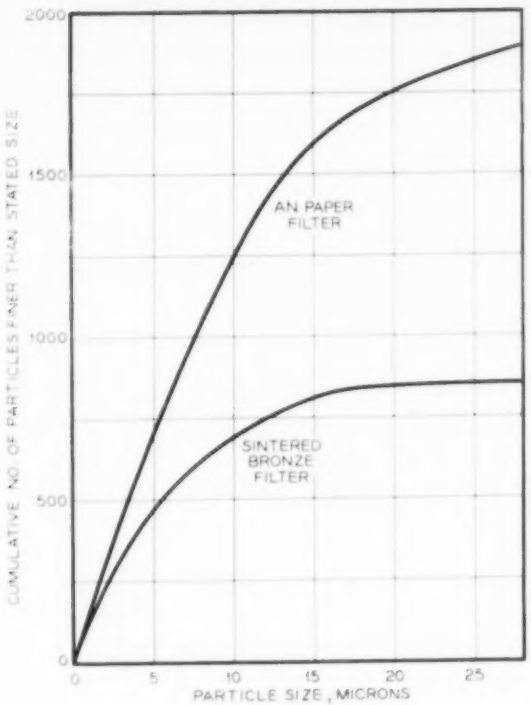


Fig. 1 (left)—Comparison of filtering efficiency of sintered bronze filter vs. AN paper filter, both filters carrying identical manufacturer's ratings for flow and efficiency. Twice as many particles were found in a 10 cc sample of the effluent of the AN paper filter, and this paper filter passed a broader range of particle sizes than did the metallic filter.

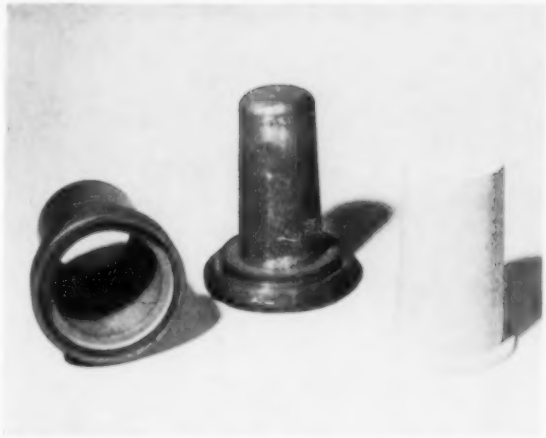


Fig. 2—Typical mold for producing sintered bronze diesel oil filter, used by the railroad industry. (Courtesy Amplex Div., Chrysler Corp.)

in the form of triangles, where each particle is adjacent to six others in the same plane. A contaminant particle, having a diam 41.4 pct of that of the material used to make the filters should be able to pass through a filter having the square arrangement of particles, whereas this would be only 15.6 pct for the triangular arrangement. However, the latter formation is much more stable and, when layer is built upon layer, it would be expected that, in most cases, any individual particle trying to work from one side of a filter to the other will encounter at least one of these triangular formations. Therefore, as a general rule, the particle entrapped by a given size filter will be equal to about 15.6 pct of the diam of the spherical particles used in that filter.

Table II gives the sizes for the maximum particles passing various grades of filter material. It will be seen that this maximum is approximately the same for the triangular geometrical arrangement of particles and the particle size calculated from the *Maximum Pore Diameter*. Although the major portion of contaminating elements coarser than the size stated in columns 2 and 3 will be removed, nevertheless some particles will pass through. Fig. 1 gives a comparison of the filtering efficiency of approved AN paper and sintered bronze filters which carry the same manufacturer's rating. Approximately 4 pct, by number, of the particles which pass through the bronze filter are coarser than the 16μ calculated from the triangular arrangement for a filter made from MD 153A filter powder. However, it is also apparent that half the particles in the filtrate are less than 5μ.

Narrow particle size distribution is desired for bronze metal powder.

In order to achieve uniform size pores, it is advantageous to obtain as narrow a particle size distribution as possible within any given grade of filter powder. A wide range of particle sizes will result in the smallest particles occupying holes in the skeleton of the coarser particles. The overall porosity will, therefore, be reduced, affecting both the permeability and the filtering efficiency. It is, however, not practical to control these particle sizes within too narrow limits. Table III lists the most common commercially available bronze filter powders. As can be seen, the *HP*, or coarser grades, have a very narrow particle size range, whereas the *A* grades have a considerably broader range. The finer grades of filter powder do not need as close sizing as the coarser grades, which is fortunate because sizing below 100 mesh would be more expensive.

Table I. Advantages of Various Types of Filter Media

Filtration Characteristics and Requirements	Paper, Resins, Etc.	Metal Screen	Bronze Filter	Stainless Steel	Ceramic
Weight	X	X			
Size		X			
Flow Rate		XX	X	X	
Pressure Drop		XX	X	X	
Re-cleanability (economy)		XX	X	X	
Ability to operate at temperatures over 350°F		X	X	XX	X
Ability to capture and retain small particles below element rating			X	X	X
Ability to remove irregular shaped particles			XX	X	X
Ability to permit passage of additives		X	X	X	X
Production volume (readily available)	X		X	X	X
Adaptability to manufacture in a variety of shapes			X		X
Strength		X	X	X	
Price	XX		X		X

XX Superior
X Good

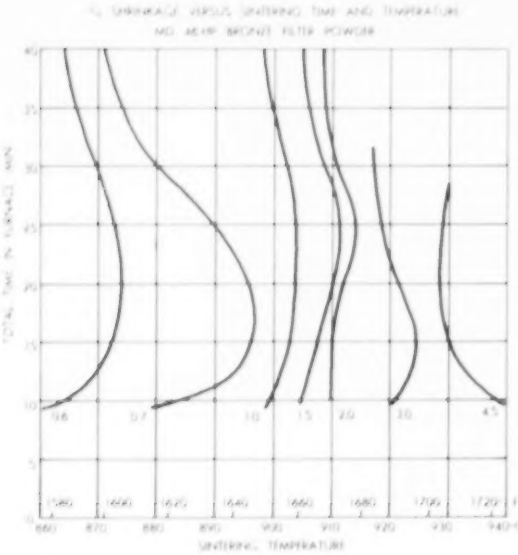


Fig. 3—Effect of sintering time and temperature on the shrinkage of MD 46 HP bronze filter powder.

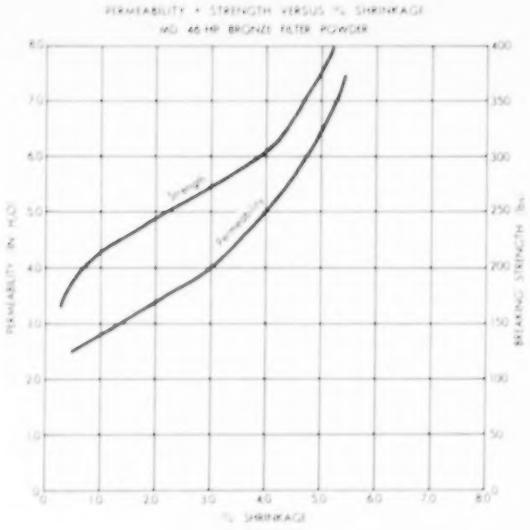


Fig. 4—Effect of shrinkage on the permeability and strength of MD 46 HP bronze filter powder.

Bronze filter powder production started from a readily available raw material, atomized copper shot. This has a Gaussian distribution of particle size, so, it is necessary to obtain the various grades of closely sized powder by screening and air elutriation. Production of any single grade is limited by the necessity for utilization of the whole range of particle sizes, either in filter powders or other products. This limitation placed a serious burden upon the growth of the industry following World War II. Therefore, a new process was developed for manufacturing the coarser grades by cutting wire to uniformly sized slugs and then forming these slugs into spheres. This is now the method used to produce the uniformly sized particles of the HP grades. The closely sized spherical copper powders are coated with a layer of a Cu-Sn alloy by a patented process to produce the powders described in Table III.

Sintered bronze filter production requires strict controls.

The procedure necessary for manufacturing sintered bronze filters is relatively simple, but control of the process, unfortunately, is somewhat difficult. A suitable bronze powder is placed in a mold having the desired shape. The mold is agitated and is placed in a furnace having a reducing atmosphere. Upon heating to about 1600° F, the low melting, high tin alloy on the surface of each copper particle tends both to diffuse into the copper, forming a bronze alloy, and to melt, forming a liquid phase, which bonds the particles together. It is desirable to reach a temperature at which a molten phase has a chance to operate as rapidly as possible, otherwise alloying will occur too fast, and the final sintered strength will usually be low. This is somewhat different from the practice with most powder metallurgy products where it is felt that the longer a piece is sintered at the proper temperature, the better will be the final products, particularly when it is desired to alloy two or more elements. A typical mold used by Chrysler for production of diesel oil filters used on most oil locomotives is shown in Fig. 2.

In making these bronze filters, lubricants do not have to be eliminated from the material. Liquid phase sintering, rather than diffusion of the tin, is considered best, provided the result is an approximate 90-10 Cu-Sn alloy on the surface of the individual particle.

Fig. 3 shows the effect of sintering time and temperature on the shrinkage of a given grade of bronze powder. The shrinkage in turn, as shown by Fig. 4, has a direct effect on the strength and permeability of a finished article. These curves, however, do not hold true if the filter is brought up to temperature very slowly, in which case the tin has full opportunity to diffuse into the copper, and full final strength is unobtainable.

In Table IV are shown the properties obtained on 1 ½-in. diam by ⅛-in. thick test filters made from the various grades of filter powder available. Shrinkage is of interest primarily to the manufacturer of filter powders, as it is by means of shrinkage that he controls his final properties, the lower values generally accompanying low shrinkage. The maximum pore diameter is calculated from the air pressure necessary to form a bubble on the surface of a filter previously saturated with a liquid. It is from this measurment that the size of the maximum particle retained on a given filter in Table II has been calculated. The breaking strength is obtained by forcing a ½-in. diam rod against the center of a 1 ½-in. test specimen, which is supported on a 1-in. round ring. In Fig. 5 the ultimate tensile strength for the various grades of metal powders has been plotted against the breaking strength normally obtained from these materials.

The pressure drop characteristics for a few representative grades of sintered bronze are shown in Fig. 6. The actual values in any given case will vary with the thickness of the filter, and in the finer grades it is not customary to use thicknesses as great as ⅛ in. The pressure drop values at a given

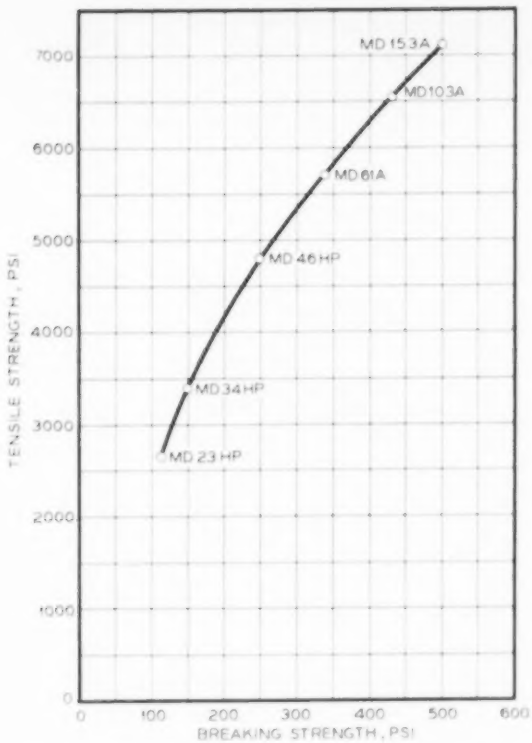


Fig. 5—Relationship of breaking strength to the tensile strength of various grades of bronze filter powders. Breaking strength is obtained by forcing a $\frac{1}{2}$-in. diam rod against the center of a $1\frac{1}{2}$ in. test specimen.

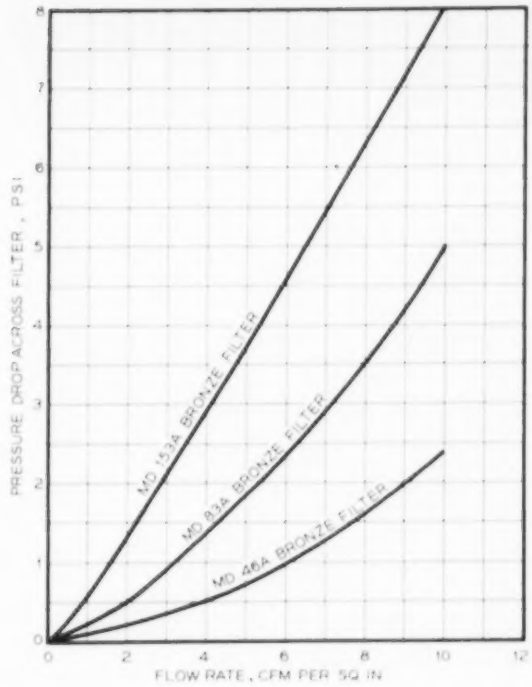


Fig. 6—Pressure drop characteristics for air flow through a 1 sq in. area of sintered bronze filters $\frac{1}{8}$ in. thick. Stainless steel filters of corresponding filtering efficiencies have identical pressure drop characteristics.

Table II. Calculated Maximum Particles Passing Filters Made from Various Grades of Powder

Grade	Calculated for Geometrical Arrangement		Calculated from Max Pore Diam (1/3 Max Pore Diam)
	Square	Triangular	
MD 12 HP	830μ	310μ	172μ
MD 23 HP	350	130	100
MD 34 HP	245	91	80
MD 46 HP	175	65	57
MD 61 A	104	39	39
MD 83 A	79	28	28
MD 103 A	62	23	21
MD 153 A	44	16	12

Table IV. Typical Properties of Bronze Test Filters

Grade	Shrinkage, Pct	Pressure Drop, Psi for 1 Cfm Air per Sq In.	Max Pore Diam (Bubble Test), Microns	Minimum Strength, Lb
MD 12 HP	0.5 to 2.0	0.01 to 0.04	400 to 725	65
MD 23 HP	0.5 to 2.0	0.02 to 0.06	260 to 400	80
MD 34 HP	0.5 to 2.0	0.04 to 0.08	200 to 330	95
MD 46 HP	1.5 to 3.0	0.07 to 0.14	150 to 210	185
MD 61 A	1.0 to 3.5	0.16 to 0.31	100 to 140	240
MD 83 A	1.5 to 3.5	0.25 to 0.50	73 to 100	275
MD 103 A	1.5 to 4.0	0.43 to 0.90	58 to 77	300
MD 153 A	1.5 to 4.5	0.72 to 1.62	30 to 45	300

Table III. Bronze Filter Powder Specifications

HP Grades

Grade	Sn, Pct	Apparent Density, G per Cu Cm	Screen Analysis, Pct					
			-10	-20	-30	-40	-50	-60 Mesh
MD 12 HP	2.5 to 3.5	4.0 to 5.0	2 Max	97 Min	1 Max			
MD 23 HP	3.5 to 4.5	4.0 to 5.0		2 Max	97 Min	1 Max		
MD 34 HP	4.0 to 5.0	4.0 to 5.0			3 Max	95 Min	3 Max	
MD 46 HP	5.50 to 6.25	4.0 to 5.0				1 Max	98 Min	1 Max

A Grades

Grade	Sn, Pct	Apparent Density, G per Cu Cm	Screen Analysis, Pct						
			-60	-80	-100	-150	-200	-325	-325 Mesh
MD 61 A	9.75 to 10.75	4.0 to 5.0	2 Max	55 to 85	10 to 35	10 Max			
MD 83 A	9.00 to 10.00	4.0 to 5.0		2 Max	20 to 45	50 to 75	10 Max		
MD 103 A	9.25 to 10.50	4.0 to 5.0			2 Max	10 to 30	35 to 55	40 Max	10 Max
MD 153 A	9.0 to 10.5	4.0 to 5.0				2 Max	30 to 60	35 to 65	10 Max

Fig. 7—Filtering unit in airline for pneumatic tools. A metallic filter is on left unit, and a porous, metallic rod is on the right unit for metering oil into the air stream. (Courtesy Amplex Div., Chrysler Corp.)

air flow can also be changed by the manufacturing heat treatment or by final treatment, such as nickel plating which is frequently used to improve the corrosion resistance and to improve the filtering efficiency.

In addition to bronze, many other metal and alloy systems have been used for making filters by powder metallurgy means. Probably the most successful of these has been the stainless steel filters which are also made from a closely sized atomized powder, although in this case the powder particles are not strictly spherical in shape. Stainless steel filters are made by placing a layer of powder on a ceramic plate, placing a weighted ceramic plate on top of this, and furnacing this sandwich in a reducing atmosphere at temperatures slightly below the melting point of the alloy involved. The filter sheet produced can then be sheared, rolled, drawn, and welded to form tubes or other shaped filters. The properties are essentially the same as the corresponding bronze grades.

Another method of making stainless steel materials is by pressing the stainless steel powder in a mold, either with or without pore forming ingredients. After sintering, these pressed materials usually have considerably greater pressure drops than the sintered sheets.

Fiber metallurgy most recent development.

The most recent development in the metallic filter industry has been the development of filters made from metallic fibers. A suspension of metal fibers is screened to form a felted mass which is then pressed and furnaced to yield the finished filter. Filters made in this way have many of the properties of a paper filter with the strength and temperature resistance of the metallic filters. Practically any metal which can be obtained in the form of fibers can be manufactured by this method.

Many applications are developing for metallic filters in the aircraft, missile, and rocket industries. Sintered bronze filters are used in the Nike, Super Nike, Terrier, Falcon, and Navajo Rockets. Since the fluid lines in these crafts are vital to the proper functioning of the vehicles, and since it is impossible to correct imperfections once one of these craft is launched, it is necessary to protect the fluid lines with the best available devices, the metallic filters. A star shaped filter now used has a filtering area greater than 35 sq in. in a length of $4\frac{1}{2}$ in. This filter is made from the finest grade of filter powder plated with nickel to provide oxidation resistance at elevated temperatures and to assure finer filtration. Nickel-plated bronze filters are also valuable for applications in the chemical industry where bronze itself would not withstand corrosion.

For bulk handling of liquids, such as petroleum and chemical products, large capacity filters are available. A typical header plate may contain as many as 54 filter elements. Here the metallic filters are valuable because they can be easily cleaned by back flushing, are resistant to chemical attack, have the strength to stand plenty of abuse, and, of course, do a superior job of filtration.

Fig. 7 illustrates two uses for the metallic filters. On the left is a cup-shaped filter used to remove moisture and foreign matter from an air line; on the right is a solid rod of filter material which acts as a wick to meter out a small quantity of oil to the air. These are but a few of the many possibilities for the use of these filter powders in industry. Filters are used for a variety of other purposes—flame arrestors, for the diffusion of fluids or gases, for dampening pressure shocks in a system and for venting systems to the atmosphere. They have the property of separating two immiscible liquids, passing the liquid with which they are wet. Chrysler has made use of this in their gasoline tank filter.

Some of the more highly publicized uses of porous metal under investigation are for boundary-layer control for aircraft and transpiration cooling of combustion chambers. The first application calls for a specially prepared stainless steel sheet which can be used on the leading edges of the flaps to suck in air. Transpiration cooling involves the passage of a cool gas through the wall of a combustion chamber in order to keep the wall cool. This is one method of overcoming the need for high temperature materials.

Cemented Carbide and Diamond Impregnated Drilling Bits

by G. C. Nalon

(who is with Metallurgical Products Dept., General Electric Co., Detroit.)

This paper, which was presented at the Powder Metallurgy Symposium of the 1957 AIME Annual Meeting, was received too late for publication in this issue of the JOURNAL OF METALS.

The paper as outlined is as follows:

I) **Application:** Description of the various cemented carbide and diamond impregnated drilling bits used in the mining and oil drilling industries.

II) **Grade Selection:** The effects of carbide particle size and binder content on the performance of cemented carbides in drilling; also a description of the grades presently employed commercially.

III) **Manufacture:** Description of the procedures followed in the manufacture of cemented carbide and diamond impregnated products.

powder metallurgy symposium

High Strength Structural Parts By Powder Metallurgy —Theory—

A discussion of the factors responsible for the strength of metals prepared by powder metallurgy and other means.

by Henry H. Hausner

IN considering the structure of metals in a general way, one may distinguish between a) metals which consist of one single crystal; and b) multi-crystalline metals. There is a basic difference between single and multiple crystal materials with respect to strength. The single crystal material usually has an abnormally high strength which could be several hundred times greater than the strength of the same metal with the multi-crystalline structure. But this is true only if the single crystal is perfect, i.e., does not contain any lattice imperfections such as vacancies, dislocations, or interstitial atoms. There is also another difference between a perfect single crystal and a multiple crystal material: the perfect single crystal deforms elastically under stress and will recover as soon as the stress is removed, whereas the multiple crystal material under the same stress will deform more plastically. The big difference between the two materials, however, concerns the defects in the lattice structure; single crystals under certain circumstances can be produced with practically undistorted lattices, whereas multi-crystalline material always contains lattice imperfections.

At the present state of knowledge in metallurgy, we believe there is sufficient evidence to say that any lattice imperfections in the single crystal will considerably lower its strength, whereas the addition of lattice defects to the already imperfect lattice of the multi-crystalline material will usually result in an increase of the strength.

Strength, like many other properties of these multi-crystalline materials, is not determined so much by the material itself, the lattice configuration, and atomic distances, but rather by the type, amount, and distribution of the imperfections in the lattice. One distinguishes between a) electronic disorders; b) excitations; c) vacant lattice sites or vacancies; and d) interstitial atoms, including misplaced lattice atoms and foreign atoms or impurities. The concentrations of these various types of imperfections are not independent of each other.

The idea that defects in the structure are the factors determining the properties of the material was developed and outlined some 20 years ago, and it was heretofore restricted to the rather limited field of solid state physics. Today it is known that the lattice distortions achieved by cold working make a metal harder and stronger, and also that the imperfection of the lattices produced by foreign atoms make an alloy stronger and harder than the pure metals.

The correctness of the dislocation theory and the effects which lattice defects exert on the physical

HENRY H. HAUSNER, is Vice President of Nuclear Engineering Div., Penn-Texas Corp., New York. This paper was presented in the Symposium on Powder Metallurgy of the 1957 AIME Annual Meeting.

properties of metals have again been proven recently by some experience in the field of nuclear engineering. By exposing an annealed metal to neutron irradiation, the bombarding neutrons knocked out some atoms from their location in the lattice, which, in turn, knocked out other atoms, so that a metal after neutron bombardment contains more lattice defects and disorders than before. The result is that by neutron bombardment the metal usually increases in tensile strength and especially in yield strength, but decreases in ductility and elongation.

Lattice imperfections of powder surface are a significant factor.

With respect to lattice defects, powder metallurgy products offer most interesting aspects. A metal powder particle is quite different from a large solid piece of the same metal because of the extremely high ratio of surface area to volume. A cubic container of 1 cm side length could take approximately 10^7 powder particles of 50μ diam, with a total surface of approximately 700 sq cm. Filled with 2μ particles, the total amount of particles in the container is approximately 10^{11}, with a total surface area of approximately 1700 sq cm.

Most of the powder particles, as small as they may be, consist of several crystals, and one frequently finds a correlation between the powder particle size and the grain sizes within the particle. Practically all the crystal lattices on the surface of the particles are more or less distorted, and the degree of imperfections depends on the fabrication method and the particle diameter. It is evident that any production of metal powder particles by mechanical comminution results in defect surface lattices. Powders made by atomization and quenching have more lattice defects *frozen* on the fast cooling surface than are present in the slower cooling particle body. Powders produced by electrodeposition with its unavoidable irregularities during production result in spongy particles with extremely large surfaces and distorted lattices. During hydrogen reduction of oxides, another method of metal powder particle fabrication, the lattices change completely from one system to another, and the changes usually result in defect structures. The different degree of lattice imperfections in the powders made by various methods explains, to a large extent, the different behavior of the powders during sintering. It is well known that practically any metal powder particle surface is slightly oxidized, and is therefore characterized by more than one lattice configuration and usually also by the presence of interstitial oxygen atoms.

Strength of green compact is largely dependent on interchange of atoms.

Compacting these millions of powder particles into a certain shape results in an agglomerate or green compact in which the particle lattice defects are uniformly and randomly distributed throughout. The strength of the green compact depends on the compacting pressure, the shape, size, and plasticity of the particles. It is generally believed that the strength of the green compact is a function of the degree of mechanical interlocking between the powder particles. This is correct, however, only to a certain degree; to a large extent the strength of the green compact depends on the interchange of atoms in the contact areas between the particles, and the rate of this interchange is probably a function of the surface lattice defects. The fact that an interchange of atoms takes place during the compacting process may be concluded from the data in Table I, which shows an increase in strength and decrease in electrical resistivity for green compacts which were kept under pressure for longer periods of time without showing any change in density. Any exchange of atoms during compacting, however, is in the direction of building up equilibrium conditions, and may therefore result in a decrease of surface lattice defects. One may regard this type of bonding during compacting as a first step in sintering.

A complete rearrangement of lattice defects takes place during compacting.

During compacting, a change in the lattice defect distribution within an individual particle takes place. We have to distinguish between the surface lattice defects, ΣD_s, and body defects, ΣD_v, which together result in the total number of defects, ΣD, in an individual powder particle. During compacting the powder particles are deformed, and an exchange of surface atoms occurs; therefore, a decrease in the surface lattice defects takes place. However, some cold work takes place, and thus the number of body lattice defects increases.

Density is only one factor in determining strength of sintered compact.

Sintering is an operation during which diffusion takes place, with the tendency towards equilibrium conditions in the particles, and a considerable decrease in lattice defects occurs. One usually correlates the strength of the sintered powder compact with its density, which is correct only to a certain degree. Density is just one factor which determines the strength of the compact; the amount of lattice defects and the movement of material and defects during the heating period of sintering determines the density and therefore the strength. The cooling period of sintering, however, hardly affects the density, but it still determines to a large degree the strength.

In a material not sintered to its full density, but characterized by a certain porosity, strength is not just a function of the density and the total pore volume, but also a function of the pore size and pore shape. The strength of a sintered material with cusp-

Table I. Effect of Compacting Time on Green Strength and Resistivity of Copper Powder Compacted at Room Temperature, with no Lubricant

Pressure	Transverse Rupture, Psi	Resistivity Microhm-Cm
Built up slowly and released immediately	5200	105
Held 2 sec	5400	101
Held 5 sec	5800	96
Held 10 sec	5800	96
Held 15 sec	4600	94
Held 45 sec	5600	97
Held 300 sec	6000	98

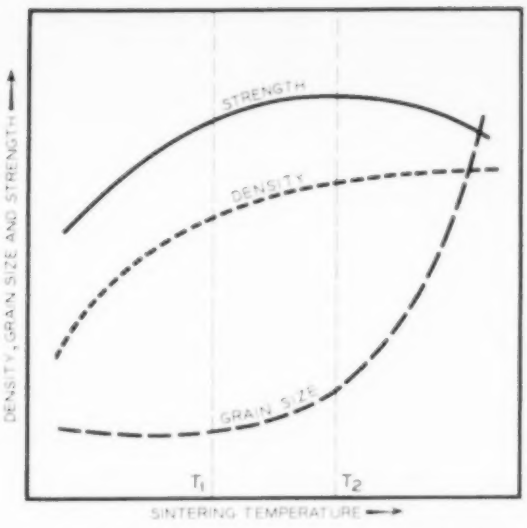


Fig. 1—Within the temperature range T_1-T_2 densification and grain growth are almost parallel, but below this grain growth is delayed by the large amount of pores.

shaped—usually termed *triangle*—pores from an early degree of sintering is probably strongly affected by the notch effects of this type of void, and it may be assumed that sintered materials with spheroidized voids will be stronger than those with cusp-shaped voids.

During sintering, a migration of lattice defects takes place which includes the vacancies and dislocations originally present in the powder particles, as well as the defects added in plastic deformation during compacting. Nucleation, originating during compacting, results in recrystallization and grain growth during sintering. Fig. 1 shows that within a certain temperature range, T_1 to T_2, of the sintering treatment, densification and grain growth are almost parallel; below this temperature range densification progresses more rapidly than grain growth which is delayed by the large amount of pores; above this temperature range, however, the rate of grain growth is much faster than the rate of densification. Grain growth is the reason why sintered materials with a higher density sometimes show less strength than sintered materials with low densities. Sintering does not only affect densification and grain growth, but acts also as an annealing treatment—as a treatment resulting in a certain ordering of the lattice and therefore strongly affecting the strength of sintered materials.

Table II. Effect of Compacting Temperature and Time on the Physical Properties of Hot-Pressed—10 Tons Per Sq In.—Electrolytic Iron

Compacting		Physical Properties			
Temperature, °C	Time, Sec	Density, G per Cu Cm	Hardness, Bhn	Tensile Strength, Psi	Elongation, Pct
500	50	6.31	50	28,000	0
	150	6.38	51	28,000	0
	450	6.71	63	40,000	1
600	50	6.70	62	37,000	0.5
	150	6.89	77	41,000	1
	450	7.05	80	49,000	2
700	50	7.32	90	48,000	1
	150	7.52	95	57,000	12
	450	7.58	100	58,000	27
780	50	7.59	101	54,000	22
	150	7.71	93	52,000	32
	450	7.76	96	53,000	37

Hot pressed materials are characterized by high strength but low ductility.

Most interesting in powder metallurgy are the materials made by hot pressing, a process which combines compacting and sintering in one step. In many cases, the applied compacting pressures are lower than those applied for room temperature compacting, and the temperatures and times of compacting are lower and shorter, respectively, than during regular sintering subsequent to compacting. The application of low temperature for only a short period of time, however, does not permit the lattice defects to migrate and practically no annealing or lattice ordering takes place. These hot pressed materials are, therefore, usually characterized by high strength but low ductility.

Table II shows the results of Henry and Cordiano's already classical hot pressure experiments on electrolytic iron. The compacting pressure in this test series was 10 tons per sq in., the compacting temperature varied from 500° to 780°C, and the compacting time from 50 to 450 sec. The maximum strength was obtained by compacting at 700°C for 450 sec (58,000 psi), with a specimen which had not yet reached full density. Compacting at 780°C for 50 to 450 sec increased the density but lowered the strength. It seems that the sample compacted at 700°C for 450 sec showed maximum strength, because optimum conditions were obtained with respect to density and lattice defects. To get high strength materials by powder metallurgy processing, these are therefore the optimum conditions.

Defects in powder metallurgy parts are randomly oriented.

Strengthening of metals by cold work, such as rolling, extrusion, etc., is well known to the metallurgist. The strengthening is accomplished by adding defects into the crystal lattices. In these cold worked materials, however, the defects are oriented in the direction in which working takes place. In a powder metallurgy product the defects are perfectly uniform and randomly oriented, which is one of the great advantages that powder metallurgy has to offer.

Experiments with respect to the behavior of powder metallurgy products during neutron bombardment have actually shown less change than with metals in which the defects are obtained by rolling or extrusion. This statement, however, is based on a rather limited experience, and additional and more systematic tests have to be made in order to fully explore the role of lattice defects on the behavior and the physical properties of powder metallurgy products.

References

[1] O. H. Henry and J. J. Cordiano: The Hot Pressing of Metals Powders. METALS TECHNOLOGY, 1945, vol. 12.

[2] H. W. Greenwood: The Fundamental Properties of Metals and Powder Metallurgy. *Metallurgica*, 1956, p. 187-188.

[3] N. F. Mott: *Atomic Structure and the Strength of Metals*. 1956, London, Pergamon Press.

[4] R. P. Seelig: *The Physics of Powder Metallurgy*. 1951, p. 344, Walter E. Kingston, ed. New York, McGraw-Hill Book Co. Inc.

powder metallurgy symposium

High Strength Structural Parts By Powder Metallurgy —Techniques—

A description of some of the techniques employed for production of the more commonly used high strength, structural materials produced by powder metallurgy.

by George Stern

THE powder metallurgy industry consumes approximately 31,000 tons of iron powder of various types per year, which certainly makes this classification one of the most important in the field of powder metallurgy. While not all parts made from iron powder can be categorized as high strength, production of such parts is growing fast.

Conditions for producing high strength ferrous parts described.

High strength ferrous parts might be considered as material having tensile strengths in excess of 50,000 psi. Broadly speaking, such high strength ferrous parts can be produced by a single pressing and sintering, a double pressing and a single or double sintering, or by an infiltration.

Single Sintering: If a single sintering is practiced, it is usually necessary to use alloying elements and high temperature sintering (in excess of 2200°F); frequently electrolytic iron powders give higher physicals than reduced iron powders. Alloying elements commonly employed are carbon in the form of graphite, copper, nickel, and manganese in the form of manganese carbonate or ferromanganese.

Double Sintering: For double sintering, as with single sintering techniques, the same considerations hold as far as alloying elements, high temperatures for sintering, and the preferred use of electrolytic instead of reduced iron powders. In many cases, where two sinterings are used, the first sintering is at a lower temperature and for a shorter time. This accomplishes a partial diffusion of alloying elements, an elimination of surface and trapped impurities, and produces a soft ductile structure. The second sintering is usually at the higher temperature in order to complete diffusion and alloying.

Since high pressures are required for the practical achievement of high strength ferrous parts having close dimensional tolerances, the use of carbide dies is extremely important. Carbide dies permit the economical use of high pressures without excessive die wear and allow the parts to be ejected from the die without the introduction of cracks or laminations.

Prealloyed stainless steel powders are finding increasing use for the manufacture of high strength parts. In this case, high pressures, carbide dies, and sintering temperatures of approximately 2350°F must be used, in a pure dry atmosphere of hydrogen,

GEORGE STERN is Vice President and Technical Director of American Sinteel Corp., Yonkers, N. Y. This paper was presented as part of the Symposium on Powder Metallurgy of the 1957 AIME Annual Meeting.

or cracked ammonia, or in a vacuum. Where close tolerances must be adhered to, a second pressing is usually employed.

A recent technique introduced in Europe, whereby hydrogen halides are present during sintering, results in the formation of high strength ferrous parts at comparatively low sintering temperatures. Specifically, when ammonium fluoride was added to a boat containing iron powder compacts during sintering at 2100°F, the elongation at fracture increased from 5 to 15 pct. An increase in strength also results for activated vs normal sintering. The halogen in the atmosphere engages in a chemical reaction with the surface of the iron particles, and sintering is accelerated.

Infiltration: The technique of infiltration is broadly employed today for making high strength structural materials. A skeleton is pressed from iron powder and may or may not be sintered as a first step. The skeleton is passed through the furnace in contact with a copper alloy which, when molten, has limited solubility in the skeleton and which penetrates throughout the skeleton body by capillary action. Upon cooling, the resulting material retains the shape and major dimensions of the skeleton and is strong, tough, and dense. It can be further heat treated for higher physical properties or machined, plated, chromized, or otherwise surface treated, brazed, welded, etc. Infiltrated parts are being increasingly used today, because they are one class of high strength material made by powder metallurgy with good impact resistant properties. Parts subjected to high loads, impact, and fatigue, and especially those parts having more than 1 sq in. of projected area, are often ruled out for powder metallurgy manufacture, unless infiltration is considered.

One of the techniques employed to prevent erosion of the skeleton when the molten copper alloy first contacts it, is the use of a *bridge*. This consists of a porous pad on which the copper alloy rests and through which it must pass before it can contact the main body or skeleton. The copper alloy thus becomes saturated with iron before it enters the skeleton and erosion is thereby minimized or eliminated.

Sintering cuprous alloys produces high strength brass.

High density, high conductivity copper has recently been made by means of powder metallurgy for a commercial application; this certainly constitutes a high strength material of its own class. The material in question exhibits excellent impact properties and has a conductivity of 95 pct IACS. It is made by pressing with high pressure and sintering in a pure, dry atmosphere.

In making high strength brass by means of powder metallurgy, it is important to get rid of entrapped lubricant and yet prevent the escape of zinc from the compact. To accomplish this, a minimum of lubricant is used to begin with, and then the compact is preburned below the temperature at which zinc volatilizes. The compacts are covered during sintering to permit a build-up of the partial pressure of zinc in the atmosphere immediately surrounding the work. This partial pressure of zinc prevents the further escape of zinc from the compact, and the result is high strength, bright, sintered brass of uniform color.

Special techniques used for high strength materials.

Hot Pressing: Hot pressing is an interesting and widely practiced method for achieving high strength materials via powder metallurgy. Carbides, borides, silicides, and other cermets are readily made by hot pressing mixtures of powders containing the metal-metalloid compound and the desired binders. The dies are usually constructed from dense, high strength, low sulfur graphite and may be heated by either their own resistance or high frequency. Various types of press arrangements may be used to apply pressure at the preferred part of the cycle. The resulting bodies are usually dense, strong, and readily made into simple shapes. Bodies of intermetallic compounds, such as nickel-aluminide, as well as heavy metal, (W-Cu-Ni) are readily made by the hot pressing technique.

Vacuum Sintering: Vacuum sintering is used for the preparation of refractory metals, such as tantalum and columbium, and certain types of cemented carbides. Titanium has also been prepared by this method. Vacuum is preferred in these cases because of the deleterious effect of most gases on these metals. In carbides containing titanium and tantalum, hydrogen sintering is harmful and therefore vacuum sintering at approximately 10^{-1} mm of mercury is practiced commercially. Recently it has also been found that superior carbides of the straight WC-Co type can also be obtained by vacuum sintering as opposed to sintering in hydrogen. Use of vacuum sintered standard carbides is increasing at the present time, and it is claimed they are stronger and more impact resistant than their hydrogen sintered counterparts. Vacuum sintered iron, stainless steel, and copper have also shown interesting physicals, especially elongation, when compared with the hydrogen sintered material.

Working Powder Metallurgically Produced Shapes: Investigation of the rolling of iron, copper, and aluminum powders has shown that excellent high strength materials can be made by first pressing and sintering a slug or ingot and subsequently working the material with intermediate heat treatments until full density is achieved. The special structures thus obtained, especially as far as fine grain size and strategically located impurities, result in interesting and high physicals, in some cases in excess of physicals obtained for like materials made by conventional melting and working methods.

Powder metallurgy has shown ability to make high strength parts.

It should be pointed out that only some of the highlights of such a vast and interesting subject as this have been touched on. Powder metallurgy has amply demonstrated its ability to make high strength structural materials. In many cases, the properties of the powder metallurgy material are so useful as to place the products in a class by themselves. Powder metallurgy materials must not always be thought of as merely substitutional for certain conventional alloys, but they must be recognized as a separate and distinct class of materials, deserving broader and more intelligent application in today's expanding technology.

powder metallurgy symposium

High Strength Structural Parts By Powder Metallurgy —Applications—

Specific details of the application of coining and resintering techniques, as well as the application of most sintering processes.

by J. M. Copeland

FOR high strength sintered parts, densities and resultant physical properties generally are higher, materials selection and engineering is more critical, tooling considerations are more important, fabricating variables must be more closely controlled, and dimensional tolerances are closer, than for conventional powdered metal parts for bearing and low strength applications.

High density means better physical properties.

Whether fabricated by multiple pressing and sintering or by infiltration techniques, high strength sintered parts should show less than 10 pct porosity. In terms of density, wrought or solid iron is 7.8 g per cu cm. Sintered iron or steel with density above 7.0 g per cu cm (or any sintered material with less than 10 pct porosity) can be described as *high density*. When highest strengths and densities are required in irons, it may be necessary to specify 7.5 or 7.6 g per cu cm minimum density.

Strength, ductility, and impact properties of low density materials are usually quite low, while ductility and strength of high density materials can be high. Fig. 1 shows a tensile bar and several high strength parts of high density iron and high density brass after fabrication by double pressing and double sintering techniques together with similar parts after twisting.

The term *sintered metal* is as broad as the term *metal*. Most wrought compositions can be duplicated by the sintering process. Material specifications have been written—often by private industry because some of the higher strength materials are relatively new—with tensile strengths ranging from 15,000 to 150,000 psi. For high strength applications, it is necessary for both designer and fabricator to work to definite and close material specifications.

Product testing in pilot plants is important.

Selection of material for a specific high strength application should be preceded by a definite program of product testing. If the shape of a given part is relatively simple and does not present a tooling problem, test parts can be machined from blanks which have previously been pressed and sintered to given material specifications.

If a part shape is not simple, it may be necessary to design production tooling and fabricate parts for model testing on a pilot production basis. A labora-

J. M. COPELAND is with the Sintered Materials Laboratory of International Business Machines Corp., Endicott, N. Y. This paper was presented in the Symposium on Powder Metallurgy of the 1957 AIME Annual Meeting.

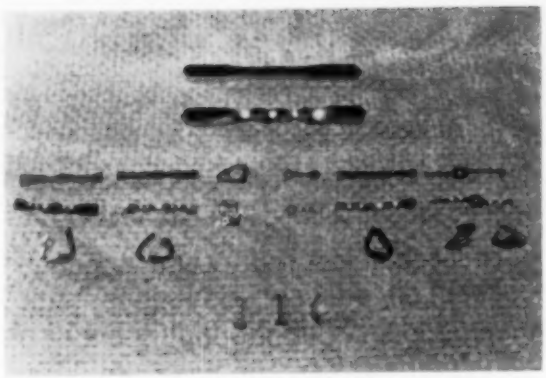


Fig. 1—Tensile bar and high strength parts made of high density iron and high density brass, fabricated by double pressing and double sintering. Bars have been twisted as a ductility test.

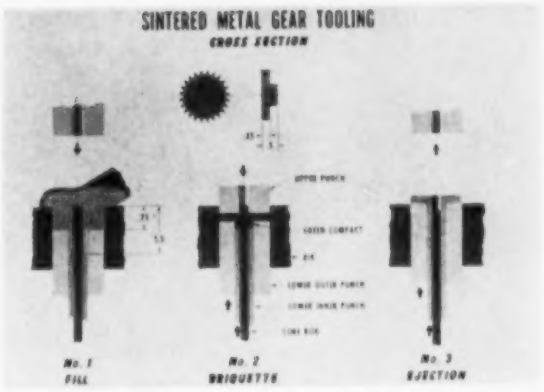


Fig. 2—Separate motions or components of tooling are necessary to produce a simple gear with hub of uniform strength and density.

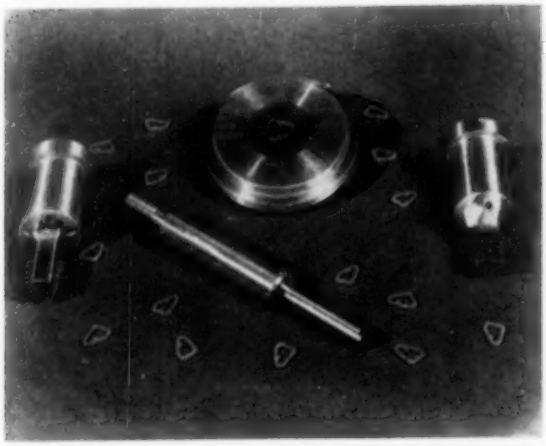
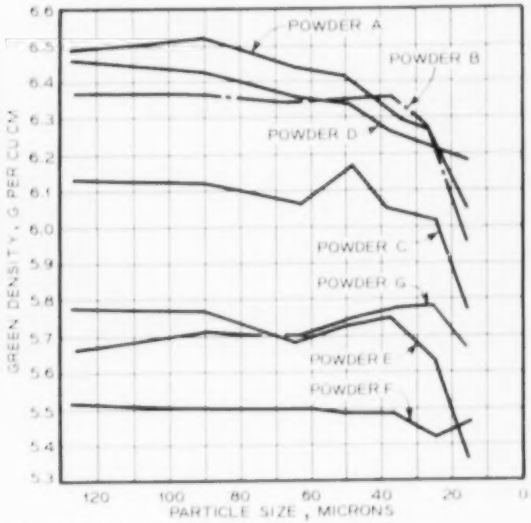


Fig. 3—Production tooling for high density iron armature pivot plate. Shown are tungsten carbide die and core rod, high speed steel upper and lower punch, and parts produced.



POWDER FRESHLY REDUCED

ORIGINAL POWDERS		ORIGINAL POWDERS	
POWDER A	6.40 G PER CU CM	POWDER E	5.78 G PER CU CM
POWDER B	6.35 G PER CU CM	POWDER F	5.54 G PER CU CM
POWDER C	6.16 G PER CU CM	POWDER G	5.91 G PER CU CM
POWDER D	6.42 G PER CU CM		

Fig. 4 (Right)—The effect of powder particle size on green compact density made it necessary to institute a performance test for raw material acceptance.

tory pilot production facility is, therefore, a requisite for any concern wishing to use sintered materials successfully for high strength parts.

Tooling design must provide for uniform density.

The design of tooling for high strength applications must provide for uniform density and strength throughout the part. This means basically separate motions in tooling for each change of thickness, or step, in a part in the direction of pressing.

For example, consider the instance of a simple gear with a hub, as shown in the sketch, Fig. 2, with a tooth thickness of 0.25 in. and a hub thickness of 0.50 in. To obtain uniform density and material properties throughout the finished part, it is necessary to compact both zones by a comparable volume ratio. Assuming a volume pressing—compacting ratio— of 3:1, the hub section must then be retracted to a distance of 1½ in. during the fill portion of the cycle. The web section will retract only ¾ in. Therefore, separate motions must be provided for each variance in thickness. A single cavity bottom punch is not practical if a part of uniform density or strength is to be made. Ejection of the pressed compact is accomplished by simultaneous movement of the bottom punches, as shown in Fig. 2.

High compacting pressures are required.

High strength parts, except in the instance of infiltrated parts, require high compacting pressures. Compacting pressures as high as 65 tons per sq in. are sometimes necessary for the pressing of high density iron and steel materials; thus, tools are subject to high abrasive forces. Therefore, it is usually

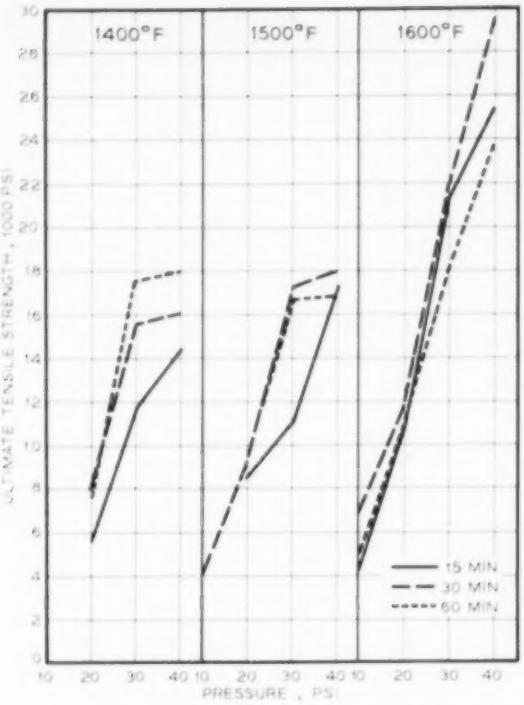


Fig. 5 (Left)—Continued dimensional and green density checking at the press are necessary in production.

Fig. 6 (Above)—Effect of varying sintering temperatures and time for an alloy brass powder compacted at several pressures.

advisable to manufacture dies from tungsten carbide. Punch and core rod components, if of sufficient cross section and of the proper shape, may be fabricated from carbide-type materials. Fig. 3 is a photograph of high density iron armature pivot plates and the production tooling used in pressing and sizing. The die insert and core rod are tungsten carbide.

High strength parts, because of their function as key components of intricate structural mechanisms, are often designed with close dimensional tolerances; 0.0004 in. in some parts are not uncommon. Some final dimensions may be obtained by finished grinding, but others are as sized and heat treated without subsequent operations.

Strict control of metal powders must be maintained.

Processing variables, beginning with specifications and acceptance testing of raw powders, continuing through the mixing, pressing, and sintering operations, and finally ending with the testing of sintered parts, necessitate controls not common to low strength powder metal fabrication.

Because of the influence of the powder variable on compacting and sintering characteristics, it has been found necessary to institute a performance test for raw material acceptance, in addition to the conventional determinations of flow, size distribution, and chemistry. Such a test is used by several members of the industry. In such tests, a powder sample is compacted in a die of specific size without additions at predetermined pressures. It is then sintered with specified furnace conditions of atmosphere and temperature. Size change of the specimen to given limits forms the basis for acceptance or rejection of the powder. Fig. 4 shows the effect of particle size variation on green density.

When high pressing pressures are used, and when relatively small parts are compressed to near 100 pct density by the use of comparatively fragile tools (often with large mechanical presses employing fixed strokes), uniformity of fill or uniformity of powder weight entering the die cavity from part to part assumes great importance.

It has been found necessary to maintain controlled and constant humidity in powder storage, mixing, and pressing areas if constant flow and filling characteristics are to be maintained in production operation. Absence of humidity control results in variance of powder flow characteristics during periods of high humidity as opposed to periods of low humidity. Batch sizes and mixing times must also be controlled in order to insure uniformity. Mixing controls must often be varied from one type of equipment to another. Continued dimensional and green density checking by the operator at the press—Fig. 5— are particularly necessary to the successful production of high strength parts.

Sintering variables need close control.

Whether the furnace be a hand pusher type or automatic, control of sintering variables cannot be over emphasized. Variables, such as sintering time,

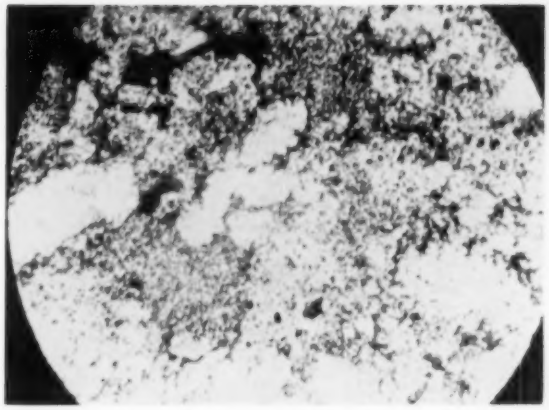


Fig. 7 (Above)—Micrograph of a commercially produced part of sintered bronze; the poor alloying of this bronze is the result of lack of control of sintering variables.

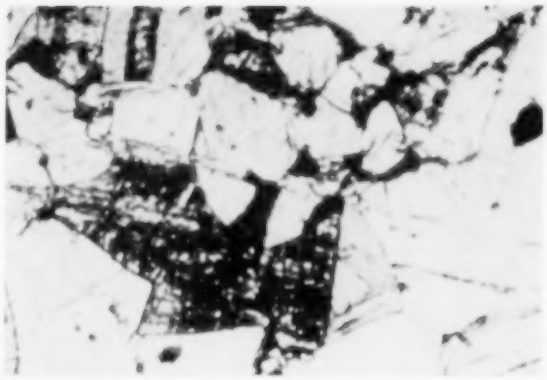


Fig. 8 (Upper right)—Alloying of a properly sintered, high density bronze part. The microstructure is scarcely distinguishable from that of a good wrought 90-10 bronze.

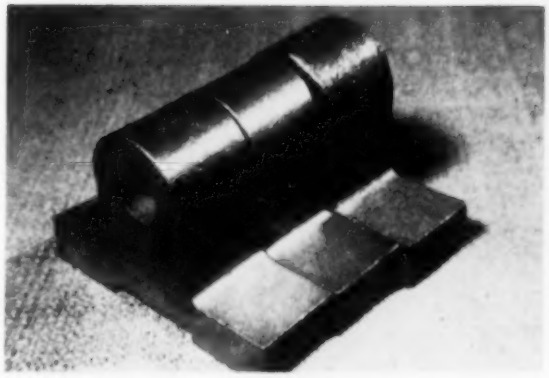


Fig. 9 (Right)—Three bronze pillow blocks produced from the same tools. Variance resulted from changing both mixing and sintering conditions.

temperature, and furnace atmosphere can determine the difference between production of uniform, high strength parts to close dimensions and production of low strength, nonuniform, inferior parts.

Optimum sintering conditions can result in a tensile strength of 30,000 psi as compared to 14,500 psi for less than optimum sintering conditions. Fig. 6 shows the effect of varying sintering temperatures and time for an alloy brass powder compacted at several pressures. Fig. 7 is a micrograph of a specimen of bronze from a commercially produced part; due to lack of control of sintering variables, almost no alloying has occurred. Fig. 8 shows the alloying of a properly sintered, high density bronze part; the microstructure is scarcely distinguishable from that of a good wrought 90-10 bronze.

With regard to dimensional control, Fig. 9 shows three bronze pillow blocks produced from the same tools; the middle part is at die size. Variance in sizes of the other two parts resulted from changing both mixing and sintering conditions.

Quality control must be based on sound sampling.

Finally, the successful commercial application of high strength sintered metal techniques requires quality control on a sound statistical basis. Dimensional checking, density determinations, crushing strengths, hardness determinations, and chemical analyses of finished parts should be closely controlled. Superficial hardness and microhardness testing equipment have heretofore had little use in the testing of sintered metals because of relatively high porosity of the materials and resultant unreliability of penetration hardness tests. Such equipment has the same place in a modern sintered metal laboratory as in any metallurgical laboratory.

Application of high strength metal techniques is resulting in an extension of the powdered metal industry.

Many parts of high density copper, brass, iron, steel, and bronze would not now be performing satisfactorily if fabricated from the low strength porous materials available five years ago.

It should be emphasized that sintered metal processes are unique in that they effect the transition from raw material to finished parts with a minimum number of steps. In any manufacturing operation they take much of the load from conventional machining departments. And finally, they lend themselves to the concept of automation. Now that it has become possible to fabricate quality sintered parts to close dimensional tolerances, the future of sintered metal products is indeed bright.

Sintered metal processes are in the initial stages of a growth cycle. They will become integrated as a part of every complete manufacturing organization. They may well eventually rank with or surpass many of the older forming methods, such as casting and forging, as a process for manufacturing high strength parts.

Ferromanganese

by J. J. Burke

• *Metallurgists have puzzled for years over how to win Ferromanganese from abundant low-grade domestic ores. Dr. Marvin Udy has now developed a process for economic treatment of New Brunswick ores. The new prototype plant, at Niagara Falls, Ontario, Canada, is operated by Strategic-Udy Metallurgical and Chemical Processes Ltd. and promises economic production of ferromanganese and iron from ores which average only 12 to 13 pct Mn and 15 to 20 pct Fe*

It is felt that the process will be equally well suited to the production of other ferroalloys from low grade ores, particularly ferrochrome. Production of iron from red mud wastes prior to acid leaching for alumina and titania is another possible application. All of these and possibly more applications are brought into the realm of possibility because of the *Udy concept* for processing low-grade ores: a continuous process carried out with minimum heat loss, where slags are upgraded in the melt to produce the desired product, thus eliminating costly beneficiation processes.

Economic Comparison of Processes for Producing FeMn

	Blast Furnace Method	Standard Electric Furnace Method	Udy Process	
			High Grade Ore	New Brunswick Ore
Ore cost, $ per ton	$68.	$68.	$68.	$ 3.
Tons of ore per ton of FeMn	2.1	2	1.8	6
Ore cost, per ton of FeMn produced	$142.	$136.	$123.	$ 18.
Kw hr per ton of FeMn produced		2400	2400	5500*
Power cost, mils		6	7	7
Total power cost, $		$ 14.	$ 17.	$ 39.
Other raw materials and operating costs	$ 43.	$ 46.	$ 49.	$117.
Total cost per ton FeMn	**$185.**	**$196.**	**$189.**	**$174.**
Selling price, FeMn	$245.	$245.	$245.	$245.
Selling price, Iron	0.	0.	0.	60.
Gross profit†	**$ 60.**	**$ 49.**	**$ 56.**	**$131.**

* Including oil substituted for power.
† Gross profit is before selling, administrative, general overhead, and all taxes.

From Low-Grade Ores

Strategic and economic considerations point to success of new process.

The strategic advantage of being able to produce ferromanganese from abundant, low-grade Canadian ore, rather than having to depend on high-grade imported ores, is obvious. The economics of such production appear to be even more encouraging. Reported costs of the Udy process and the standard processes for producing ferromanganese are summarized in the table. It should be noted that the process can also use high-grade ores on a competitive basis. The second table gives a detailed breakdown of the $174 cost figure of the Udy process.

The key factors—production of iron as a byproduct and use of low cost ore—promise an even greater advantage when the company's full scale plant is completed at Woodstock, N. B. Hard by the company's ore reserves of some 250 million tons, the new plant will have an annual capacity of 75,000 tons of ferromanganese and 75,000 tons of ingot iron. Power cost at the Woodstock site is not anticipated as a problem, nor is transportation of products from the plant. Hydro and steam power should be available at about 7 mils by the time the plant goes into production. Woodstock is 160 miles by rail from St. John, N. B., an all year, deep-water port. Opening of the St. Lawrence Seaway will provide ready access to all major U. S. steel centers.

The process: selective reduction with heat economy.

The flow sheet used in the prototype plant is shown in Fig. 1. New Brunswick ores are of two types: *Red*, containing 13.5 pct Mn and 20 pct Fe, and *Gray*, containing 12 pct Mn and 15 pct Fe. The Red ores go through a preliminary flotation step to remove silicious material. They are charged into the rotating, oil-fired kiln in equal parts, together with 300 lb of limestone added to each ton of ore. The kiln serves to remove chemically combined water and to give a uniform charge to the reverb at about 1000°C. Weight loss on ignition is about 13 pct. The discharge from the kiln, with iron almost entirely in the form of FeO, goes into two insulated hopper buckets, shown in Fig. 2. These are used to keep the kiln product hot while transfering to the reverb. Eventually, the kiln will discharge directly into the reverb, with the hot gases from the reverb serving to preheat the charge.

A reverbatory furnace was chosen for melting to conserve electric power. The *bonus* power in the reduction, described below, might well make this unnecessary in the full scale plant. The reverb in the prototype plant has oil burners mounted on two sides and located under the charging holes in the roof. Any Fe_2O_3 left is here reduced to FeO. Slag in the reverb is held at a base:acid ratio of 1:1.

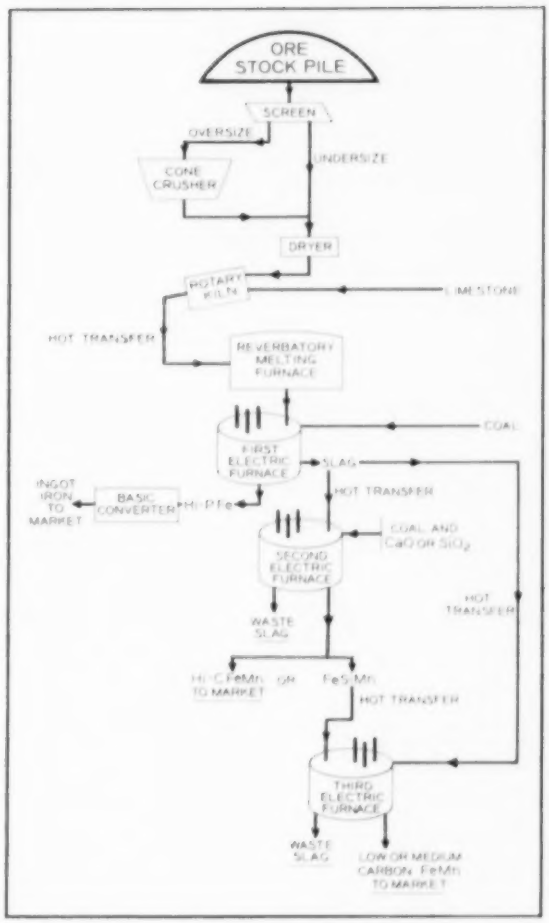


Fig. 1—Flowsheet of the prototype plant at Niagara Falls, Ontario.

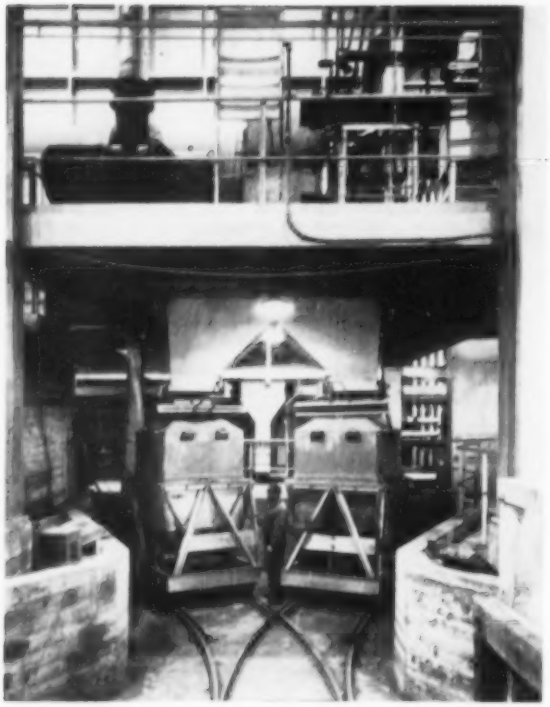


Fig. 2—The rotating, oil-fired kiln (upper left) discharges into these two hopper buckets which are designed to reduce heat loss while the charge is transferred to the reverb.

Cost Break-down of Udy Process with New Brunswick Ore

	Quantity Per Ton FeMn	Unit Price	Cost Per Ton FeMn	
Ore	6.0 Tons	$3.00	$18.00	
SiO_2	nil		0	
Lime	1.4	10.00	14.00	
Coal	0.67	11.00	7.50	
Power	5500 Kw-hr	7 mills	38.50	
Electrodes*	180 lb	10¢	18.00	
Oil	280 gal	10¢	28.00	$124.00
Labor (operating)	10.0 man-hr	$2.00	20.00	
Maintenance			15.00	
Supplies			3.00	
Refractories			2.00	
Cooling H_2O			2.00	
Plant Overhead			8.00	50.00
Total				$174.00

* Carbon electrodes @ 10¢ lb vs. 20¢ lb for graphite electrodes.

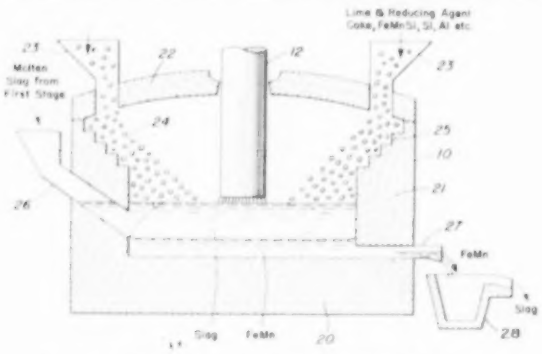


Fig. 3—Specially designed electric furnace eliminates hot spots around the electrodes which cause vaporization of manganese.

Tapping temperature is 1350°C, and there is about a 50° loss in the transfer to the first electric furnace. It is important to note that no fluxing materials have been added up to this point except the limestone that was added to the kiln charge.

In the first electric furnace, the temperature of the melt is restored to 1350°C before any reducing agents are added. The furnace design is similar to the third furnace, shown in Fig. 3. There are many advantages to this design, and this, perhaps more than anything else, provides the key to the Udy concept. In conventional furnace practice, the electrodes are immersed to a depth of around 5 ft in the mix, and coke has a tendency to segregate under the electrodes and cause local hot spots, where manganese vaporizes; close temperature control is thus very difficult. In the Udy furnace, a molten charge is introduced, and after it has come to temperature, reducing agents are added at the side, where they come in contact with the melt and go into solution without any chance of segregation. The electrodes are positioned from ½ in. above to 2 in. below the surface of the slag, but the arc pressure keeps them from actually being wetted. In this manner, it is possible to control the temperature to within 100°C of the melting point of ferromanganese, thus eliminating the possibility of vaporizing manganese. The weight of the fluxes on the melt keeps the melt away from the sides of the furnace, thereby reducing erosion of the refractory lining.

In this furnace, just enough coal is added to reduce preferentially the FeO, which settles quickly to the bottom, because the reacting material is all liquid. A temperature of 1350°C is maintained throughout. The surprising feature of this stage of the operation is the small amount of power necessary to effect the reduction. Addition of reducing agents at this point causes what seems to be an exothermic reaction (which might be a violent change in the reaction rates). This *bonus power* caused the total power consumption for the process to be considerably lower than the original estimate.

Tapping the iron leaves a large volume of slag which contains 16 to 17 pct Mn and 3 pct Fe. This is, in effect, a high grade manganese ore. Total loss in volume from the original kiln charge is 28 pct at this point. The base to acid ratio of the slag is raised to 1.5:1 with the addition of lime.

The iron, tapped out of the first electric furnace, contains 3.5 pct P (due to high phosphorus in Brunswick ores), 1 to 2 pct C, and 0.1 pct Mn. If this is treated in a basic converter with oxygen to remove the phosphorus, an ingot quality of iron is produced.

Work in the second and third electric furnaces is predicated on the type of product desired. Additions of coal and lime or silica in the second furnace will produce either a high-carbon ferromanganese or a ferrosilicon-manganese. Ferrosilicon-manganese can be charged into the third furnace with slag from the first furnace to produce either medium or low-carbon ferromanganese. Naturally, additions of carbonaceous matter are kept to a minimum at this stage.

Should the process prove as successful in full production as it appears in the prototype plant, and should it prove equally well adapted to the processing of low-grade ores of other ferroalloys, it will indeed have a strong impact on the mining and production of these products from abundant domestic supplies which, up until this time, have been economically unfeasible to work.

Cobalt Pressure Leaching and Reduction At Garfield

by J. S. Mitchell

Cobalt recovery from arsenical concentrates by pressure leaching and reduction involves special methods and operating problems. Principal steps in the process are auto-oxidation acid leaching under pressure, filtration of the tailings, purification of the solution, hydrogen reduction of the ammoniacal solution, and melting in an electric arc furnace to remove sulfur and granulate the metal.

EXTRACTING cobalt metal from arsenical ores has presented a major metallurgical problem for many years. In acquiring the Blackbird mine near Salmon City, Idaho, in 1943 Calera Mining Co. accepted the challenge to solve this problem.

Originally much experimentation and piloting had been carried out on a process involving two or three stages of roasting, followed by leaching and chemical separation of cobalt metal from the leach liquors. However, before plant design had been started, Calera became interested in a new process, which was sponsored by Chemical Construction Corp. and appeared to offer considerable simplification, lower operating costs, and better recovery. It was decided to adopt this scheme, in spite of the fact that it had not been piloted.

For various reasons, which need not be discussed here, developing the process presented more difficulties than were anticipated. Calera struggled with this situation for more than a year, solving many of the more serious problems and producing a substantial amount of metal, but it also became obvious that more equipment would have to be installed and a much longer period of costly mechanical and process development would be required before a commercial rate of production could be expected. Considering these circumstances, Chemico agreed to undertake responsibility for this continued development, and during their period of operation (nearly two years) real progress was made. By the end of this time it had been demonstrated that an agreed production rate could be obtained, with acceptable recovery and cost factors.

In December 1955 Calera reassumed operation of the plant, and since that date it has operated satisfactorily. Efforts to improve processing are continuing. Costs can be lowered considerably, partly through continued mechanical improvements which, it is hoped, will greatly lower maintenance costs on the high pressure equipment. Various possibilities for improving metallurgy are being diligently explored.

The complex beneficiation of the ore at the mine produces a cobalt concentrate, that is treated at the company's refinery near Garfield, Utah, and a copper concentrate that is shipped to custom smelters.

J. S. MITCHELL is Plant Manager at the Garfield Refinery of Calera Mining Co., Garfield, Utah.

Analysis of Concentrate Arriving at Garfield Refinery, Pct

Cobalt	17.50
Iron	20.00
Arsenic	24.00
Sulfur	29.00
Nickel	1.00
Copper	0.50
Insoluble	5.00
Moisture	12.00

Concentrate: The concentrate arrives at the refinery in railroad boxcars in approximately 50-ton lots. The material is removed from the cars with mechanical loaders and temporarily stored in individual bins pending subsequent blending and introduction to the plant system. Each carload lot

maintains its identity up to the time it is charged to the concentrate mix tank.

On the basis of arsenic and iron content the concentrate is blended to achieve a ratio of approximately 1.20 As:1.00 Fe. This ratio is an important factor in achieving optimum chemistry in the oxidation autoclave.

The concentrate is repulped with process water or dilute process liquors to a pulp density of 1250 to 1300 or approximately 25 to 27 pct solids.

For all practical purposes the subsequent handling of this slurry is achieved with conventional agitation and pumping equipment. When slurry is transferred from the initial repulping tanks to storage feed tanks the material is passed over a vibrating screen for removal of debris and oversize that may interfere with subsequent pumping.

Up to this point, no serious operating problems have been encountered.

Oxidation: This operation is carried out in a horizontal pressure vessel 40 ft long and 6 ft in diam. The shell is of carbon steel with 3/16-in. cladding of type 316 stainless steel. In addition to the cladding, the vessel has a 12-lb lead lining and acid brick.

The lead lining is an additional safeguarding feature, installed at the time the first acid brick lining was replaced after approximately three years of service. Inspection of the stainless clad after the failure of the initial acid brick lining revealed that, in spite of the precautions taken, the clad had been attacked to a considerable degree.

The autoclave is divided into six equal compartments by acid brick walls with overflow weirs, which allow the oxidation slurry to flow from one compartment to the other. Each compartment contains an agitator mechanism to provide mixing and aeration. Provisions are also made to sparge air into each compartment.

Concentrate slurry is introduced to the first compartment by means of Manton-Gaulin high pressure positive displacement pumps. The original pumps were of the triplex plunger type. Severe abrasion and corrosion resulted in extremely high maintenance costs; consequently these units were replaced with Mantan-Gaulin Hydrex pumps. These newly developed hydraulic displacement pumps are giving acceptable service at this time.

Addition of concentrate, process solutions, and recycled process slurries and the discharge of the oxidized slurry is a continuous operation. Operating level is controlled by a Gagetron.

The chemical reaction is exothermic, producing an oxidation slurry containing free acid, cobalt, nickel, iron, and copper as sulfates and minor amounts of arsenic in solution, also iron-arsenate and calcium sulfate as an insoluble residue. Operating pressures are maintained at over 500 psig and temperatures in the various compartments are over 375°F.

Exit gas from the autoclave (oxygen deficient air and steam) is exhausted through scrubber towers to the atmosphere. Oxygen utilization from the compressed air introduced to the reactor approximates 60 pct.

Oxidation process solubilizes 95 to 97 pct of the cobalt. However, there are small losses of soluble cobalt in the subsequent filtration step.

To the uninitiated, the process explained thus far seems quite straightforward. As far as flow of material is concerned, this is true. The problem of containing the process was another matter. During early stages of development many difficulties were encountered in mechanical operation of the oxidation autoclave. Gasket and valve failures were frequent, and packing life of the agitator shafts was of short duration. Prior to acquiring titanium bolts and fasteners (at the time under development, with slow delivery) the agitator impellers fell off at the rate of one per week. At this point it might be mentioned that corrosion resistance of even the best stainless steels against the hot slurry is almost nil.

Gas let-down from the vessel (operating pressure to atmospheric) took its toll in various alloy valves. Stainless steel valves, fittings, and fastenings literally dissolved under the severe operating conditions of both erosion and corrosion, and service life was short.

After many months of *cut and try* with design and materials of construction, these items were improved to a considerable degree. In almost all instances these critical parts have had to be developed and then fabricated locally. Until recently no suitable substitute had been discovered for the titanium and ceramic that went into the slurry and gas discharge valves. The importance of titanium for agitators and discharge piping cannot be overstressed. More recently tantalum and Refrax R and silicon carbides have shown promise for these applications.

Filtration and Solution Purification: Acid slurry, discharged from the oxidation autoclave, is substantially neutralized by addition of limestone and hydrated lime. Some precaution is necessary at this step to avoid precipitation of cobalt hydroxide. Formation of this compound would result in its loss with the insoluble iron arsenate-gypsum residue that is discarded to waste in subsequent filtering operations.

Filtering of the oxidation slurry is achieved on conventional drum filters fitted with stainless steel drums and hard rubber decks. Polyethylene filter cloths are used on all drum filters. To reduce soluble losses to a minimum, the usual procedures of repulping, refiltering, and displacement washing are carried out. Dilution of the primary filtrate is controlled to a cobalt concentration appropriate to the subsequent reduction operation.

Further purification of the process solution is necessary to remove the residual iron (that amount that was in excess of the stoichiometric requirements to form iron-arsenate in the oxidation autoclave), arsenic, and copper. The iron and arsenic are removed conventionally by addition of hydrated lime, anhydrous ammonia, and air. This process is a batch operation, carried out in steam-heated rubber-lined tanks. Proper aeration and temperatures of approximately 140°F are considered essential. The above procedure produces a residue of gypsum, iron hydroxide, and minor amounts of iron-arsenate. The resulting slurry is filtered on precoated drum filters to give an iron and arsenic-free solution. The residue is recycled to the oxidation autoclave, as it contains appreciable cobalt values. The filtrate is advanced to a subsequent batch process wherein the copper is removed by simple cementation with cobalt powder.

The cementation step produced some unexpected results. To attain an acceptable time cycle for this operation it was necessary to introduce excess amounts of cobalt powder. This naturally produced a copper cement sludge that contained appreciable percentages of cobalt. This represented a *tie-up*, as

well as a copper cement that was not marketable. However, a process has now been developed whereby these cements have been retreated, yielding the copper and cobalt as separate products.

Hydrogen Reduction: The reduction step is a batch process carried out in vertical autoclaves of approximately 450-gal capacity. These vessels are fitted with agitators, hydrogen spargers, and steam jackets.

The purified solution produced in the previously mentioned steps is now ready for the reduction process. Anhydrous ammonia is added in controlled amounts to produce a complex cobalt ammine. The resulting solution is pumped into the reduction autoclaves, and heated to about 375°F; compressed hydrogen is admitted, and in the presence of a catalyst, the cobalt is reduced to a fine metal powder, grey in color with an apparent density of 4 to 5. Total operating pressure is 750 to 800 psig.

An operating cycle consists of a *seed run* and several *densifications*. In the seed run, formation of the metal powder is a result of the catalyst, which produces a fine metal powder. In the subsequent densification runs the powder from the seed run acts as the nucleus to produce powder of increased particle size and density, depending on the number of densifications.

From an operating standpoint the mechanics of the gaseous reduction phase appear to be simple. It might be said that the combination of pregnant solution, catalyst, and a controlled hydrogen atmosphere produces cobalt powder. This is all very well, but it does not account for the considerable percentage of cobalt metal that ends up as a dense metallic plating on the interior surfaces of the reduction autoclaves. Extensive research in the field of agitation, catalysts, and chemical composition of working solutions resulted in decreased amounts of this plating; however, the condition continues to exist.

When these deposits were first encountered they were removed by manually chipping with pneumatic hammers. This was costly, laborious, and time-consuming. However, this method was the only practical way that could be used at the time. Reduction capacity was limited to four autoclaves and *down time* had to be minimized. In the interim, additional autoclaves were acquired which provided increased capacity, making feasible the development of an *acid leach* for removing plated deposit.

To add to the problem, removing the deposit by chipping produced a platy product (several thousand pounds per vessel) that required considerable treatment before it could be recycled to the plant flow. A technique has now been developed whereby the material has been converted to a marketable product.

A further problem encountered in the reduction step was the production of cobalt metal powder that contained excessive sulfur impurity. This sulfur is present as entrapped gypsum particles and to some extent as contained ammonium sulfate. The latter can be removed in part by successive displacement water washes and subsequent decantation or filtration.

Initial process design had called for calcining the powder in a hydrogen atmosphere followed by compacting in a conventional pelletizing press. Since the powder did not meet sulfur specifications, a further refining step became necessary before a saleable final product could be produced. This problem was solved by the installation of an arc furnace.

The fact that the gaseous reduction step did not produce complete conversion of the cobalt content of the feed solutions to metallic powder presented another unexpected problem, with accompanying loss of metal. Conversion is in the neighborhood of 97 to 98 pct. It was also discovered that some redissolution is experienced if the metal powder is allowed to remain in contact with the reduction end liquors. Consequently these liquors and wash water are now treated with ammonium or sodium sulfide to produce a cobalt sulfide precipitate, which is filtered out, and subsequently returned to the oxidation step.

Added to the above mentioned process problems were mechanical weaknesses. Agitator mechanisms were a recurring source of operating delay, partly because of repeated failure of packing glands. Discharge valves also failed frequently as a result of erosion experienced in handling the powdered metal slurry while taking a pressure drop of some 800 psi. Gasket failures were an everyday experience.

Initially the autoclaves were fitted with internal steam coils. These coils often failed at the welds, resulting in contamination of condensate and presenting further difficulties in the steam plant. Even the operation of a relatively simple steam trap became a problem when cobalt-bearing solutions found their way into the system. However, during their period of operation, Chemico replaced the heating coils with external steam jackets, which have eliminated this particular problem.

Arc Furnace: The powdered metal produced in the reduction step contains on the average 0.15 pct sulfur. This material is charged into a size *Q* Lectromelt furnace and melted down in the presence of a high lime slag. Minor amounts of coke are added, and some pig aluminum for degassing the metal is charged just prior to the pour.

Pours are made as soon as a sulfur analysis indicates that the metal is within specifications. By this time the bath has reached a temperature of approximately 2800°F. The molten metal is poured into a pit of water to form granules. Temperature and rate of pour have a decided effect on the physical characteristics of the final product. The granules are collected in a basket suspended in the pouring pit. Subsequently, they are dried, polished, and packed in steel containers for shipment.

Analysis of Final Products, Pct

Cobalt	95.60
Nickel	3.90
Sulfur	0.03
Iron	0.20
Arsenic	0.03
Copper	0.02
Carbon	0.15

Summary

As the first such plant of its kind to be put into production, Garfield refinery had many new and difficult problems. In a period of three and a half years many of these have been solved, while others still await a proper solution.

Development work continues in an effort to simplify various phases of the process. At this time, much is being done toward replacing batch operations with continuous flow. It is firmly believed that the remaining problems related to continuity of operation can be solved in the near future, with further improvements in recovery and cost.

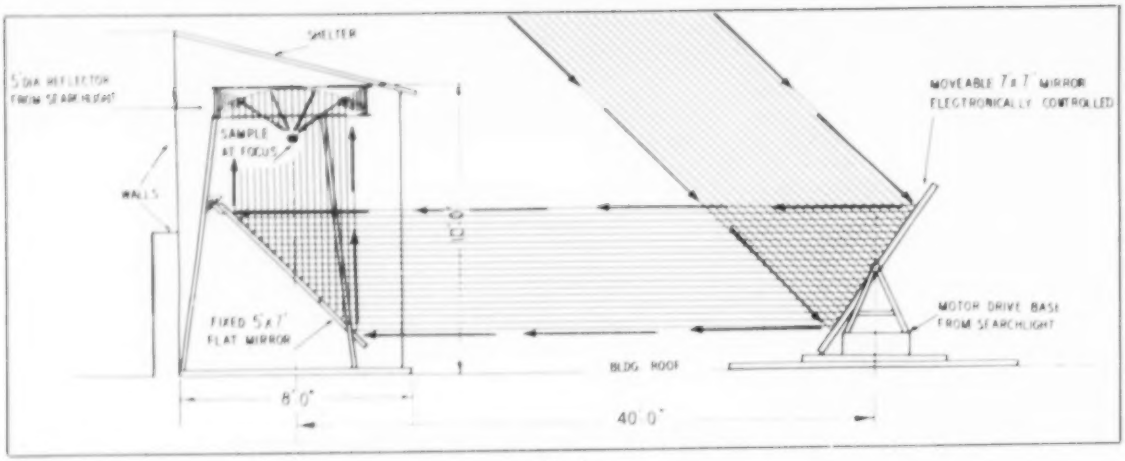


Fig. 1

Nonferrous

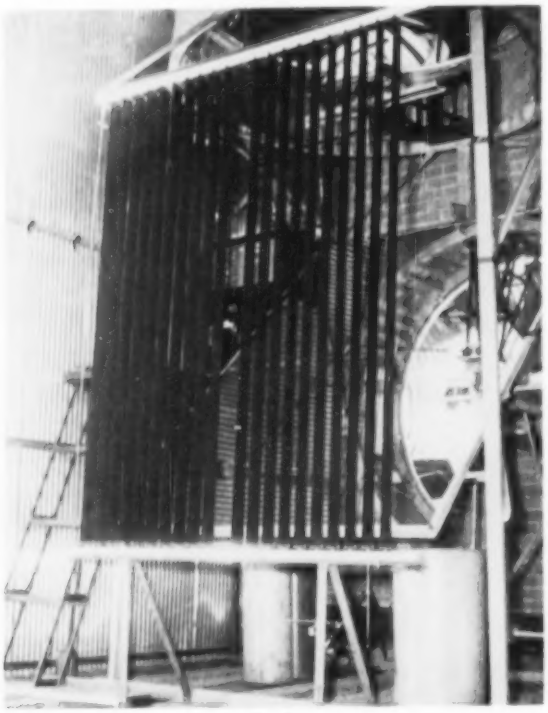


Fig. 3

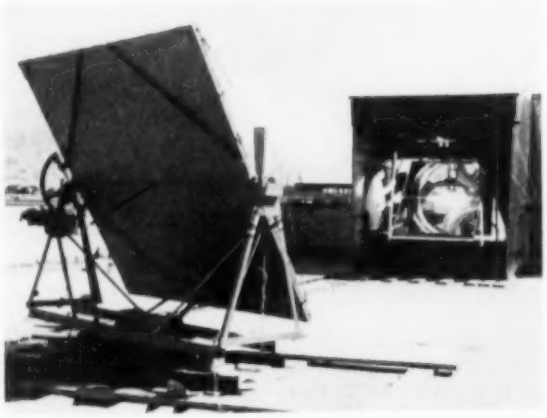


Fig. 2

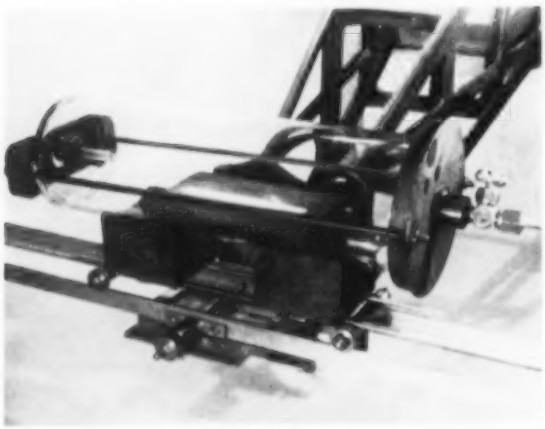


Fig. 4

Fig. 1—Diagram of the completed solar furnace installation at the Kennecott Research Center. Temperatures of over 3000°K have been achieved.

Fig. 2—Solar furnace was made of 60 in. searchlight. Sun's rays are reflected from 7x7 ft heliostat at left to fixed 5x7 mirror at base of parabolic reflector at right.

Fig. 3—The manually controlled vertical blind is used for controlling the temperature in the furnace. One slat has been left out of the center for purposes of focusing and photocell control operation.

Fig. 4—The sample chamber, with a Pyrex cylinder and track mounting, allows zone refining experiments to be conducted in protective atmospheres. The machined carbon block inside the cylinder supports the sample.

by W. M. Tuddenham

Research Uses Solar Furnace

AT Kennecott Research Center in Salt Lake City, a solar energy furnace recently has been built for the purpose of conducting research in the field of nonferrous metallurgy. The principal objectives of the research center are:

1) to develop techniques for increasing the recovery of copper and other minerals from Kennecott's operating properties,
2) to improve methods of recovering valuable byproducts,
3) to assist the firm's Exploration Dept. by evaluating new sources of metals,
4) to find better and less costly methods of extracting metals from ore, and
5) to improve the quality of refined copper.

In all of these phases of activity, pyrometallurgical techniques play an important role. The effects of various furnace atmospheres on smelting procedures are of particular interest to the pyrometallurgist. Specialized techniques, such as vacuum fusion and zone refining, are becoming increasingly more important in research and in production of high purity metals. Molybdenum, rhenium, and columbium are examples of important metals that require special purification and fabrication techniques because of their high melting temperatures and affinity for gases, such as oxygen and nitrogen.

It was felt that a solar furnace, being a high intensity source of pure heat under controlled conditions of pressure and furnace atmosphere, would be valuable for research, not only in the fields mentioned above, but also in other projects. The additional feature of being able to fuse samples in such a way as to avoid contamination from the container was also of interest. One of the most appealing features of the solar furnace as a research tool was its apparent adaptability to problems of many different types. Experience, thus far, has shown this adaptability to be a most valuable feature.

W. M. TUDDENHAM is with the Research Center, Kennecott Copper Corp., Salt Lake City. This paper was presented at the Solar Furnace Symposium of the Association for Applied Solar Energy, Phoenix, Ariz., January 1957. Proceedings of the conference will appear in the Journal of Solar Energy Science and Engineering.

Searchlight with modified heliostat mounting used.

The idea of building a solar furnace at the Kennecott Research Center was conceived in the spring of 1955. Upon investigation, it was found that a 60-in. war-surplus searchlight was available, and plans were made to utilize this as the nucleus for a solar furnace unit. Consideration of the type of problem that was expected, coupled with discussions with others in the field, led to the conclusion that a modified heliostat mounting should be used. This offered maximum flexibility and convenience in sample handling even though it was recognized that the maximum temperatures to be expected would be lowered because of increased aberration and reflection losses. Research Center personnel designed and constructed the unit. The cost, exclusive of research time, has been approximately $3400, of which $1400 was for materials and $2000 for labor. Fig. 1 is a diagram of the furnace installation.

The sun's rays are reflected from the 7x7-ft heliostat to a fixed 5x7-ft flat mirror and thence to the horizontally mounted 5-ft diam parabolic reflector. As far as possible, those portions of the original searchlight that were adaptable were used. Since the unit was installed on the roof, relatively lightweight construction was necessary. The partially dismantled searchlight base was used to hold the heliostat. Fig. 2 is a photograph of the completed installation.

Parabolic Mirror: The new parabolic mirror used in the unit is front surfaced and is constructed of

copper with a rhodium plating. The characteristics of this type of searchlight reflector, as summarized by Conn,[3] are as follows:

Characteristics of Parabolic Reflector from a 60-in. Searchlight

Aperture	60 in.
Focal length	25¾ in.
Focal length/aperture	0.43
Effective conc. surface	19.6 ft sq
Theoretical image diam	0.24 in.

Benveniste and Hiester[2] have reviewed the dimensions listed and their meanings in terms of solar furnace efficiency. It is worthy of mention that these searchlight reflectors are, generally speaking, quite satisfactory for small solar furnace applications.

Auxiliary Mirrors: As shown in Figs. 1 and 2, the furnace has two auxiliary reflectors. These reflectors are commercial plate glass mirrors with electrolytic copper backing. The frames are constructed of welded 1-in. angle iron with ¾-in. plywood backing. Two 3½x5-ft mirrors are used for the fixed reflector and four 3½x3½-ft mirrors are used for the heliostat.

Heliostat Installation: The heliostat installation utilizes wires and turnbuckles for alignment of the mirror. This arrangement has not been entirely satisfactory, and a modified mounting is under consideration which would not only be more rigid but would also allow individual alignment of the mirrors. Following the suggestion of Trombe,[5] it is planned to decrease the size of the individual mirror elements to 20x20 in.

The original searchlight base was modified and used as a mount for the heliostat. The original drive motors were replaced with reversible, fractional horsepower Barcol PYAZ motors geared down to approximately 1 rpm. A further reduction of 150 to 1 was accomplished through the gear drives in the searchlight base. Back lash in the gears is taken up by applying a constant pull through a system of weights and pulleys.

Heliostat motors are controlled by plate relays which are actuated by photocells through a modification of a circuit described by Radio Corp. of America.[4] Two photocells are used: one to control the elevation and one to control the azimuth drive of the heliostat. These photocells are placed in collimating tubes mounted vertically at the periphery of the parabolic mirror. The circuit is so arranged that the azimuth motor drives until sunlight strikes the azimuth control photocell. In the morning, the elevation drive works in a similar manner. During the afternoon, however, the action is reversed and the motor drives until the sunlight no longer strikes the elevation control photocell. The small shift in the position of the focal spot in changing from morning operation to afternoon operation is easily compensated for by moving the sample mount slightly. The correction error for this control unit is of the order of ±1′ of arc. A manual circuit is used for initial positioning of the heliostat.

Temperature Control and Measurement: The temperature control unit for the furnace consists of a so-called vertical blind, which at present is controlled manually, but could easily be adapted to automatic control. As shown in Fig. 3, the center and side of the unit were left open in order to assure continued operation of the photocells. This arrangement also functions as a focusing aid when the blind is closed.

Sample Chamber Provides Protective Atmospheres.

Although much solar furnace work is successfully done under oxidizing conditions, this is not possible when working with metals. It was, therefore, necessary to devise a sample chamber capable of furnishing either protective atmospheres or high vacuum. In order to study zone refining techniques, it was further necessary to provide a means of passing samples through the focus. The sample chamber and mounting use a 4-in. diam Pyrex cylinder set upon carbon blocks; a machined carbon block is used to support the sample inside the chamber, as shown in Fig. 4.

The original searchlight arc mount was modified to hold the chamber and allow its movement along three axes. For zone refining studies, the frame holding the sample chamber is pulled along the rails at the desired rate so that successive portions of a rod of the material being studied are passed through the focus.

Furnace Temperatures Over 3000°K Reached.

Furnace temperatures have been measured by fusing materials of known melting point. Magnesium oxide, which has a melting point over 3000°K, has been melted in this furnace.

The final installation and testing of the Kennecott solar furnace was finished late in the summer of 1956; consequently, no completed projects can be reported. In order to test the amenability of the furnace to the types of research mentioned earlier, several preliminary experiments have been completed. It has been found that the furnace is capable of fusing a columbium sample, which melts at 2770°K, under vacuum in the sample chamber. It was not possible, however, to attain 3420°K, the melting point of rhenium. A sufficient number of zone melting experiments have been conducted on samples of fire refined copper and on alumina to indicate that the solar furnace with its ancillary equipment is adaptable to this technique.

Proposed Furnace Modifications.

The furnace has proved itself to the extent that it is felt worthwhile to proceed with such modifications as will further improve its performance and versatility.

It was observed, soon after putting the furnace into operation, that the heliostat was causing a considerable amount of aberration because of misalignment of the individual mirrors. It has also been observed that a more rigid frame for supporting the heliostat is desirable so as to minimize the effect of wind. Plans are underway at least partially to correct these difficulties.

In addition to Kennecott's research, interest in using the unit has been expressed by the University of Utah, and it is anticipated that the furnace will have a full schedule for many sunny days to come.

Bibliography

1. G. Benveniste: *Solar Energy Furnaces*. Stanford Research Institute, Menlo Park, Calif., 1955.
2. G. Benveniste and N. K. Hiester: *Mech. Eng.*, 78, 915, 1956.
3. W. M. Conn: *J. Franklin Inst.* 257, 1-12, 1954.
4. RCA Manufacturing Co., Inc.: *Phototubes*, 1940.
5. F. Trombe: *Proceedings of the World Symposium on Applied Solar Energy*, p. 63, Stanford Research Institute, Menlo Park, Calif., 1956.

Annual Powder Metallurgy Symposium — 1956

Dispersed Hard Particle Strengthening of Metals

A review is presented of the various methods utilized to strengthen metals and alloys for high temperature service by a suitable dispersion of finely divided hard particles. Alloys such as SAP, produced by powder metallurgy, and other sintered aluminum powders, molybdenum containing small quantities of refractory oxides and magnesium containing a dispersed intermetallic, are considered. Internal oxidation and other methods of achieving a hard particle dispersion are discussed. New data on the high temperature strength and stability of the alloy systems Cu-Al_2O_3, Ni-Al_2O_3 and Be-Be_2C are shown. The theoretical aspects of the hardening and strengthening mechanism are presented and consideration is given to the problems associated with the powder metallurgy of the various processes.

by Nicholas J. Grant and Oliver Preston

PUBLICATION of data by Irmann[1] indicating outstanding thermal stability and elevated-temperature strength properties in a sintered aluminum powder product (SAP) stimulated interest in the strengthening of metals by means of a highly dispersed oxide phase.

This material was produced by compacting, sintering and extruding a fine flake aluminum powder, resulting in a dense product containing 10 to 16 volume pct alumina, which arises from the thin oxide film on the starting powder, highly dispersed in a matrix of pure aluminum. The method of producing SAP, and the stable high-temperature properties obtained from it, introduced the possibility of developing superior materials for high-temperature service by powder metallurgy methods.

The composition of the materials of this type which are presently under consideration is predominantly metallic, containing from less than 1 pct up to about 20 volume pct of the oxide. As a result, other properties of these materials, such as electrical and thermal conductivity, thermal shock resistance, and to a certain extent ductility, notch sensitivity, machinability and hot working properties, are also predominantly metallic.

These alloys do not constitute, therefore, a completely new class of materials as do the cermets, but rather present a new means of modifying the properties of a metallic matrix. In this sense, SAP type alloys are more closely analogous to the alloy aging systems. While the strength properties realized in the oxide-pure metal systems at the lower temperatures are substantially less than the best attainable in the aging systems, the thermal instabilities in the latter make them of less value for use at temperature much above their optimum aging temperatures, as indicated in Fig. 1. While the means of obtaining an oxide dispersion are more difficult and costly than conventional aging processes, in the light of the as yet limited understanding of such systems there is considerable promise of improved high temperature properties arising from the thermal stability of these structures.

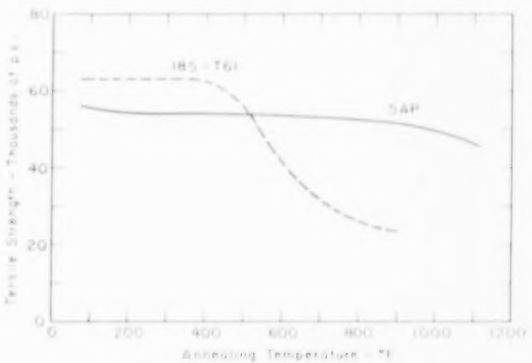


Fig. 1—Tensile strength at room temperature after exposure of 100 hr at temperature for SAP and 1 hr for 18S-T61.

Since the development of SAP in 1946, its properties and the properties of a series of similar Al_2O_3-Al products containing from about 1 to 20 pct aluminum oxide have been fairly extensively studied and reported.[1-5] Particular attention has been given to

N. J. GRANT, Member AIME, is Associate Professor, and O. PRESTON is Research Assistant, Department of Metallurgy, Massachusetts Institute of Technology, Cambridge, Mass.

TP 4400E. Manuscript, May 7, 1956. New York Meeting, February 1956.

The Transactions papers appearing in the JOURNAL OF METALS *during 1957 will subsequently appear in AIME Transactions Volume 209, and may be permanently referenced to that volume.*

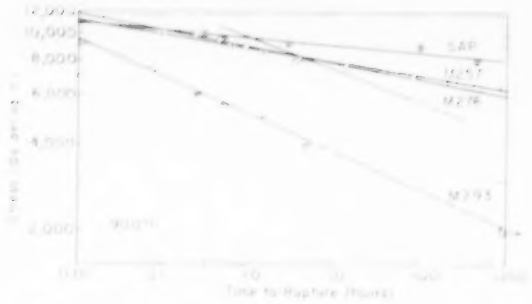


Fig. 2—Log stress vs log rupture life for various Al-Al_2O_3 alloys at 900°F. Alloy XF 18S-T61 at 600°F is shown for comparison with the wrought powder products.[6]

creep-rupture[1-3] and fatigue properties[1,2] at temperatures up to 900°F. Fig. 2 summarizes the results of creep-rupture tests made at 900°F on four alloys containing from 2 to 20 pct Al_2O_3 and compares the results with those of one of the best known high temperature age-hardenable wrought aluminum alloys, XF18S-T61, tested at only 600°F. Not only has there been a gain of 300°F by several of the oxide-metal alloys at useful engineering stresses but there is also a large improvement in rupture life (and creep resistance) even at the 300°F higher temperature. Of particular importance to the high temperature metallurgist are the unusually flat slopes of the curves of Fig. 2 for the higher oxide materials, showing a temperature-time stability of unusual proportions.

While these stress-rupture properties are quite outstanding for an aluminum-base material, particularly at the longer rupture lives, the temperature of application is still nevertheless limited for many applications by the intrinsic properties of the matrix metal, notably its melting point. Since the most urgent need at present is for materials to operate at temperatures above 1000°F, and especially above 1600°F, for gas turbine blade materials for example, and in view of the success with the aluminum-aluminum oxide alloys, a considerable amount of attention has been directed toward the problem of producing a highly dispersed hard particle phase in a matrix of a more refractory metal or alloy. The hard particle in known instances has been oxide, carbide, silicide or boride. Of considerable importance at this early stage of development is that some effort has been directed toward a study of the fundamental mechanisms of strengthening through the presence of a dispersed phase, introduced by powder metallurgical means; although at best the effort is much too small.

Results of Some Preliminary Studies

With respect to the problem of obtaining the oxide phase in highly dispersed form, most of the methods being considered depend primarily on the techniques of powder metallurgy. The most direct method employs simple mechanical mixing of the desired quantities of the oxide and metal powders, by either dry or wet ball-milling, followed by compacting, sintering and extruding as in the case of the Al-Al_2O_3 alloys.

The applicability of mechanical mixing methods to produce oxide-metal alloys is illustrated in Fig. 3 for a copper-10 volume pct alumina alloy. Fig. 3, a log stress-log rupture life plot, shows the 350° and 450° curves for the copper-alumina product in comparison to the 350°C curve for wrought pure copper. Not only is the copper-alumina product stronger at 450°C than pure copper at 350°C, but the slopes of the curves for the powder product are extremely and characteristically (for this type of alloy) flat. The flat slope, as in the case for the Al-Al_2O_3 alloys in Fig. 2, is a meaure of the thermal stability of the structure at 450°C.

If a comparison is made of the stress for a 1000 hr rupture life, the copper-alumina alloy is four times as strong as pure copper at 350°C and is still three times as strong 100°C higher (at 450°C). Based on a rupture time comparison at 350°C and 16,500 psi, the admixture of 10 pct (volume) of Al_2O_3 to pure copper increased the rupture time from about 0.05 hr to about 1000 hr, approximately a 20,000 times increase in life.

Thus, in spite of an as yet incompletely understood process, large gains in strength at elevated temperatures have been achieved.

Significant gains were also achieved in the room temperature yield strength with this same product. Table I shows the results of tests performed on wrought pure copper and on the Cu-10 pct Al_2O_3 alloy.

Heating of the Cu-10 pct Al_2O_3 alloy to 800°C resulted in only a small loss of hardness over the as-extruded condition, again in agreement with the results attained with the Al-Al_2O_3 products.

These results are somewhat surprising, for several reasons. Relatively coarse copper (−200 mesh) was used, and virtually no comminution was obtained in the mixing operation. Mixing was far from optimum in view of the many unknown aspects of the art, and some significant segregation of alumina was noted

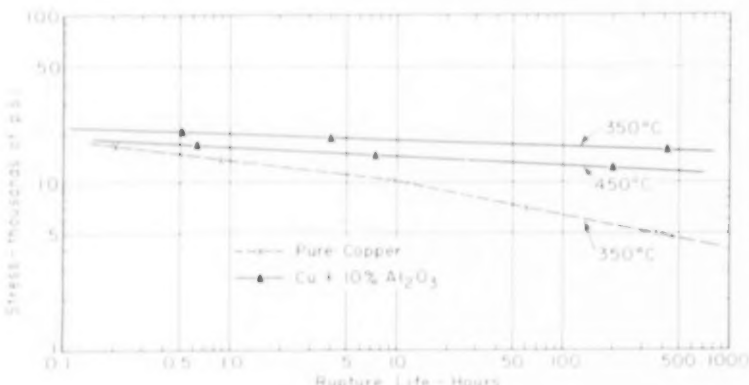


Fig. 3—Log stress vs log rupture life for wrought pure copper at 350°C and for Cu-10 volume pct Al_2O_3 at 350° and 450°C.[5]

in the microstructure, see Fig. 4. (The above results have been taken from the more extensive work of Klaus Zwilsky of this laboratory.[5])

Supporting these encouraging results on alloys made from mechanically mixed powders are the data recently obtained with much finer nickel powder (−10 μ) mixed with fine alumina. In tests at 815°C (1500°F), a Ni-10 pct (volume) Al_2O_3 alloy showed similar improvements over wrought pure nickel as that noted for the copper-alumina system, namely, an increase of four to five times the stress for rupture in 200 hr, and a 10,000 times increase in rupture life at 815°C and 5,000 psi (0.2 hr for pure nickel vs 2000 hr for the Ni-Al_2O_3 alloy). Once more limitations of mixing efficiency pose the important problem of achieving even better alloys. These results are from the work of Walter Cremens of this laboratory.[7]

Bruckart, Craighead and Jaffee[8] have recently reported on the effects of dispersions of various oxides in molybdenum, obtained by powder metallurgy techniques. These involved both mechanical mixtures of the oxides with fine molybdenum powders, and deposition of the oxides by decomposition of certain nitrates and acetates. Significant improvements in creep and stress-rupture properties were noted in some cases with only very slight oxide additions, as seen in Fig. 5. The small amounts of oxide, while only slightly increasing the room temperature tensile strength, were found to have a marked effect in restricting grain growth at the higher temperatures. It was noted during vacuum annealing of molybdenum that the presence of small quantities of

Table I. Yield Strength and Ductility of Copper and Cu-Al_2O_3 Product

Product	Yield Strength (0.2 Pct Offset), Psi after 1009°C Anneal, 1 Hr	Elongation, Pct	Reduction in Area, Pct
Pure copper	7,900	52	94
Cu-10 pct Al_2O_3	30,200	15	7

oxide at the grain boundaries continued to inhibit grain growth; growth occurred only after the oxide content was diminished to extremely low level.[9] Such cases are to be compared with thoriated tungsten light filaments, in which both grain growth and creep are restricted by the presence of small amounts of the oxide phase.

Internal oxidation of powders offers an especially important means of obtaining a highly dispersed oxide phase in a metal matrix. If an alloy consisting of a dilute solution of a base metal in a more noble solvent metal is oxidized under suitable conditions of temperature and oxygen pressure, oxygen diffuses into the alloy to precipitate small dispersed particles of the oxide of the solute metal without the formation of a surface oxide of the more noble solvent metal. The basic mechanism of internal oxidation or subscale formation was proposed by Smith[10] in 1930. Meijering and Druyvesteyn[11] showed that appreciable hardening could be achieved through internal oxidation in alloys of copper and of silver. De Jong[12] has reported high creep resistance in Be-Cu alloys after internal oxidation.

More recent work by Martin and Smith[13] covering both single crystals and polycrystalline solid specimens of dilute copper alloys showed a marked improvement in creep resistance at 200°C for poly-

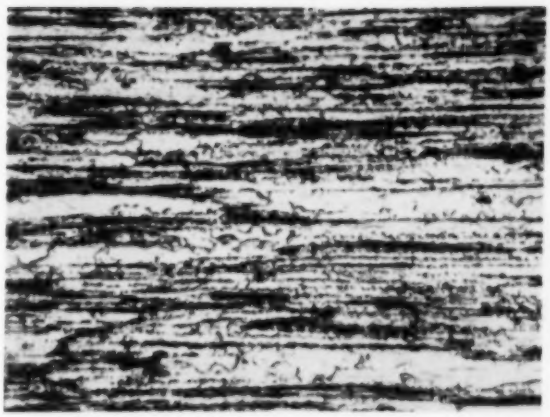


Fig. 4—Longitudinal section of extruded Cu-10 volume pct Al_2O_3 alloy. Note Al_2O_3 segregation and regions of coarse copper powders. Etched with potassium dichromate etch. X500. Reduced approximately 20 pct for reproduction.

crystalline samples of a Cu-0.05 pct Al alloy internally oxidized at 850° and 900°C. Much of this improvement was retained after an annealing treatment at 1000°C, as shown in Fig. 6. It was further noted, Fig. 7, that the creep resistance increased with decreasing temperature of the internal oxidation treatment. The mean size of alumina particles produced by internal oxidation at both 850° and 900°C was estimated to be 500A. Smith and Gregory[14] have recently studied the tensile properties of internally oxidized silver alloys both at room temperature and at elevated temperatures.

Dispersions of hard and stable phases other than oxides should, of course, also receive similar extensive consideration. An interesting case involving a dispersion of an insoluble intermetallic compound by powder metallurgy means was reported by Busk and Leontis.[15] Powders of Mg-0.6 pct Zr and of the Mg-Al eutectic were mixed, followed by compacting, sintering and hot-working. Subsequent thermal treatment caused diffusion of the zirconium and aluminum, bringing about precipitation of a fine dispersion of the Al-Zr compound, which is insoluble in the magnesium matrix even above its melting point. Yield strengths of 45,000 psi and tensile strengths of 50,000 psi at room temperature were reported for magnesium alloys produced in this manner. While the high-temperature properties were not studied, the materials showed marked resistance to grain growth and retention of mechanical properties even after prolonged annealing treatments. Similar properties were reported by these authors on Mg-MgO materials analogous to the Al-Al_2O_3 alloys, in spite of the use of a rather coarse flake magnesium powder.

Interesting results are reported by Greenspan wherein pure beryllium powder was mixed with fine carbon, pressed, sintered and hot extruded.[16] The results of creep rupture tests at 1200° and 1350°F are shown in Table II.

Be_2C, which is essentially insoluble in solid beryllium, is much more finely and uniformly dispersed than if the alloy were made by melting. The results in Table II show the large benefits derived from making the alloy by powder methods. In fact, the creep rupture strength of the powder product at 1350° is considerably greater than that of the pure berryllium at 1200°F, and once more shows the

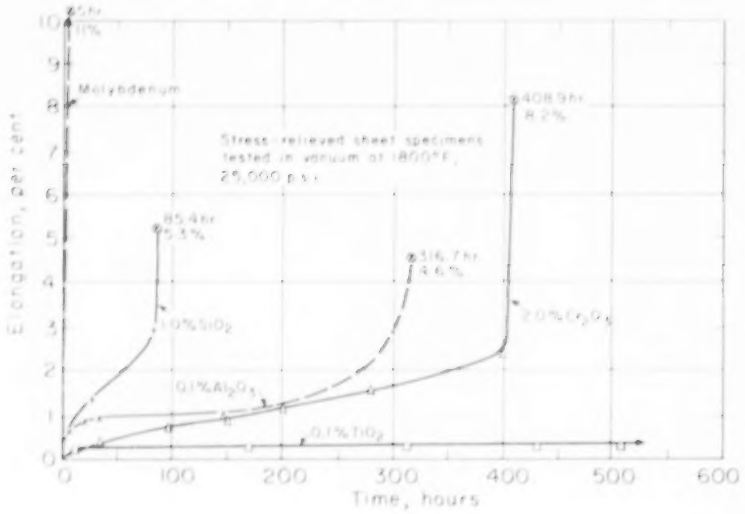


Fig. 5—Effects of dispersions of small quantities of various oxides on the creep of molybdenum at 1800°F.[5]

characteristic flat slope in a log stress-log rupture time plot.

It is clear that the possibility exists of producing dispersions of insoluble intermetallic compounds in other metallic systems by similar means to those described above or by mechanical mixing of the metal and the intermetallic.

Working with platinum wires produced by powder metallurgy, Middleton, Pfeil and Rhodes[25] noted a marked increase in recrystallization temperature over that of the conventional cast and wrought metal, which they attributed to the presence of a small amount of suitably dispersed porosity. Improved creep resistance and stress-rupture properties were also reported for the powder product. While the validity of the explanation of increased resistance to recrystallization imparted by the presence of slight porosity has been questioned, sintering studies on copper by Alexander and Balluffi[27] clearly showed that the location of grain boundaries after prolonged heating at temperatures near the melting point is to a certain extent controlled by the voids present. The effect of voids in this respect is similar to the blocking effect of boundary movements due to the deoxidation products in killed steels. It would appear that the stabilizing effects which the voids or dispersed phase exert on the grain boundaries make an important contribution to the strength of these materials at the higher temperatures.

In fact, studies of grain boundary migration in creep clearly support the importance of holes or voids as well as of extra phases on the restriction of the movement of the grain boundary. Fig. 8 shows the restraining effect of a small pin indentation and an etch pit on the migration of a boundary. Once the surface energy is overcome, however, the boundary quickly straightens out to assume a lower energy position.[28]

Theoretical Considerations

Any system of two or more phases, whether originating by a precipitation reaction, phase decomposition, internal oxidation, or produced by means of mechanical mixing, must be considered as undergoing strengthening through dispersion hardening to some extent. The extent of strengthening is in general dependent upon the nature and degree of dispersion.

A great deal of work has been done on precipitation hardening systems, which constitute a very important field of alloys. An extensive review of precipitation hardening data was made by Geisler,[16] who attributed the strengthening for the most part to the effects of coherency strains set up in the matrix by the precipitated particles with only a very minor contribution from dispersion hardening. While there is no evidence available at present to indicate that such coherency strains exist in the oxide-metal systems, it is conceivable that strains of a similar type might arise through interfacial free energy relationships even in the case of mechanical mixtures.

Theories of dispersion hardening have been proposed by Mott,[29] by Orowan,[30] and more recently by

Table II. Be_2C Extruded Powder Product

Material	Stress, Psi	Rupture Life, Hr
	1200°F	
Pure beryllium	10,000	0.2
	5,000	1.6
	2,500	35.0
	1,500	455.0
Be + C powder product*	10,000	4.0
	7,500	22.0
	5,000	181.0
	3,000	2800.0
	1350°F	
Pure beryllium	2,000	0.95
	1,000	8.0
	700	22.0
	600	164.0
Be + C powder product*	5,000	2.55
	4,000	29.3
	3,000	860.0

* Contains 0.8 pct C, equivalent to about 2.5 pct Be_2C.

Fisher, Hart and Pry,[31] expressing strength as a function of particle spacing, derived from the interaction of dislocations with the dispersed phase.

An earlier work by Gensamer and co-workers[32] on a number of irons and carbon steels in various conditions of heat treatment showed a linear relationship between yield strength and the logaritnm of the mean free ferrite path between carbide particles, as shown in Fig. 9, taken from a later work by Roberts, Carruthers and Averbach.[33]

An investigation has been made[5] relating mechanical properties to microstructure in Al-Al_2O_3 alloys.

A typical microstructure of SAP containing 13 pct alumina is shown in the electron micrograph of Fig. 10 at X20,000. The spacing between oxide particles was measured for a series of such materials covering oxide contents from 1 pct to 17 pct. These values (surface to surface) ranged from 0.35 to 2.2 μ with decreasing oxide content. The strength at various temperatures from room temperature up to 900°F is plotted in Fig. 11 against the reciprocal of the average interparticle spacing. The straight line relationship indicates agreement with Orowan's theory of dispersion hardening in this range of interparticle spacings. The plot of strength vs logarithm of spacing in Fig. 12 does not show the straight line necessary to satisfy Gensamer's relationship. Using internally oxidized Ag-0.05 pct Al specimens, in which the size and spacing of the alumina particles were varied by varying the temperature of the internal oxidation treatment, Gregory[8] found agreement with Orowan's prediction and disagreement with Gensamer's.

On the other hand, data presented by Lenel, Backensto and Rose,[6] on Al-Al_2O_3 alloys prepared under somewhat different conditions, such that a more distinct flake Al_2O_3 particle results than shown in Fig. 10, appear to favor the Gensamer relationship.

The theoretical considerations discussed thus far were originally based on strength evaluations at the lower temperatures, where plastic deformation is predominantly through the mechanism of slip. At the higher temperatures, where the usual form of slip is often not apparent, or is absent, and the role of the grain boundaries becomes increasingly important in the deformation process, the emphasis in the study of dispersion hardening must not be directed solely at the effect on strength within the grains, but on the effect of the dispersed phase in strengthening and immobilizing the grain boundary. No data have been published relating specifically to this area of research, although the effectiveness of the small oxide content in the molybdenum work previously discussed tends to suggest that the amounts and locations of the dispersed phase in this case give rise to increased creep resistance, primarily through interaction with the grain boundaries.

It has been observed in many cases that the resistance to recrystallization and the creep strength at elevated temperatures are not directly related to the amount of the oxide present. Fig. 13 shows the strength of SAP type materials as a function of oxide content at various temperatures. This cannot be interpreted as indicating directly the increase in strength with increasing oxide content, since the higher oxide contents are obtained through the use of finer aluminum powders. Thus, a large part of the strength increase must be attributed to the decreased oxide spacing as previously discussed. The curves for the higher temperatures must also be interpreted with caution, since it is not possible to show in Fig. 13 or in Fig. 11 the effect of the higher oxide content or smaller oxide spacing in reducing the slope of the stress-rupture curves. Fig. 14 shows the actual benefits achievable at longer times, 1000 hr, as a result of increased oxide content or, more accurately, as a result of the decreased average interparticle spacing. In this plot it is also obvious that the benefits of the fine alumina dispersion are equally great at 900°F as at the lower temperatures when the long time stability is take into consideration.

Further observations concerning the strength of oxide-metal systems and of dispersion-hardened systems in general may be made from studies of cermets and sintered carbides. In an investigation of tungsten carbide bonded with cobalt, Gurland and Norton[9] showed that the high strength of these materials did not arise from a rigid carbide skeleton as had been previously believed. It was determined that the cobalt bonding metal showed a strength many times greater than that of the same material in bulk form. They pointed out that restraint of plastic yielding of a metal increases its flow stress to values approaching the fracture stress, in the same manner that the strength of a soldered or brazed joint may show values five or more times that of the bonding metal.[10] They also considered the effects of stresses set up in the cobalt bonding phase through the differential contraction between the carbide and the bond during cooling from the sintering temperature. It is possible that similar stresses may arise in the matrix adjacent to the oxide particles in the oxide-metal systems, analogous to the coherency strains in precipitation hardening.

In studies of crystal breakdown, Wood[11] had proposed that the minimum crystallite size which is achieved after severe deformation is of the order of 10^{-5} cm. Further fragmentation will not take place readily and fracture will occur. It has been sug-

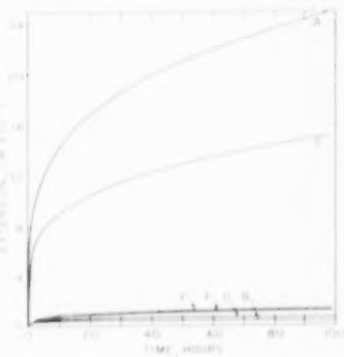


Fig. 6—Creep of copper and internally oxidized Cu-0.05 pct Al alloy at 200°C and 3.1 tons per sq in., after Martin and Smith.[12] *A*, pure copper annealed at 850°C; *B*, Cu-0.05 pct Al internally oxidized at 850°C; *C*, pure copper annealed at 900°C; *D*, Cu-0.05 pct Al internally oxidized at 900°C; *E*, Cu-0.05 pct Al oxidized at 850°, then annealed at 900°C; and *F*, Cu-0.05 pct Al oxidized at 900°, then annealed at 1000°C.

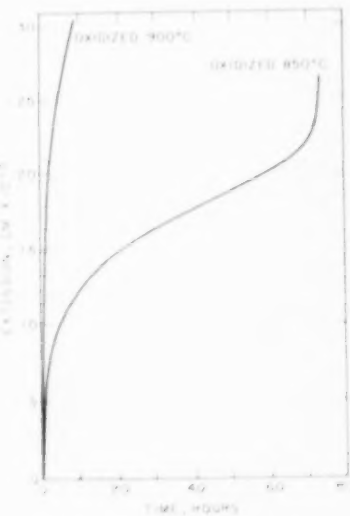


Fig. 7—Creep of internally oxidized Cu-0.05 pct Al alloys at 200°C and 5.12 tons per sq in., after Martin and Smith.[12]

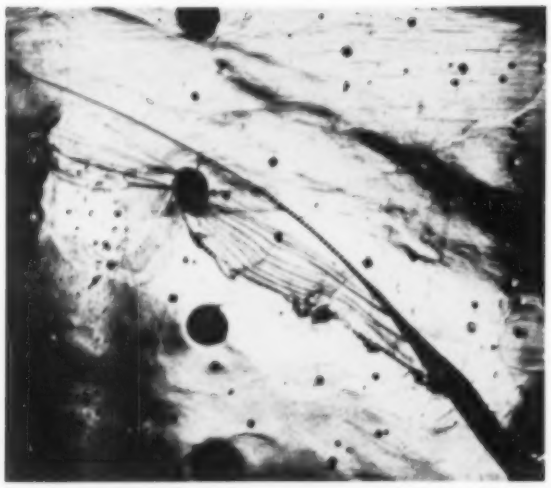


Fig. 8—Restraining effect of a small indentation on the movement of a grain boundary during creep in pure aluminum at 700°F. X50. Reduced approximately 15 pct for reproduction.

gested that the resistance of SAP to deformation at elevated temperatures is due to a powder size which is already at approximately 10^{-4} cm. The ultra-fine flake aluminum powder therefore represents an alloy at the minimum particle or crystallite size in which recrystallization and grain growth are prevented by the fine Al_2O_3 barriers.

In fact, studies of SAP show that cold work (up to a maximum of about 29 pct) increases the hardness and tensile strength very little.[7] Efforts to recrystallize either the as-extruded or the 29 pct cold worked SAP have been unsuccessful, although the hardness increase through cold work is recoverable on high temperature annealing, see Table III.

This suggests that energy equivalent to a large amount of cold work already exists in the Al-Al_2O_3 structure, as indicated schematically in Fig. 15.

A further measure of the stored energy in the Al-Al_2O_3 alloy is evidenced in Figs. 11 and 13. If the room temperature curves are extrapolated to 0 pct Al_2O_3, a value of tensile strength of 19,000 psi is indicated for pure aluminum, which is considerably higher than that expected for annealed pure aluminum.

On the other hand, if annealed powders are used, as in the case of copper[7] with a powder size considerably larger than 10^{-4} cm (—200 mesh, for example), mixed with 10 pct alumina, and followed by extrusion as a final step, a very strong alloy is obtained as described above, which shows high temperature strength and stability. It must follow that at the high extrusion rates used, sufficient strain hardening of the matrix must occur, including fragmentation to a small crystallite size approaching 10^{-6} cm, to give the necessary strength plus the stability of the structure as insured by the recovery and recrystallization blocking effects of the finely dispersed hard phase.

Accordingly, severely cold worked powders are not a necessity to produce a strong product. Thus, the factors of powder size or crystallite size, and the importance of deformation (strain hardening) on the properties of the system, must be considered in any theoretical approach to the strengthening mechanism.

At present, no final decision can be made concerning the important mechanism or mechanisms of strengthening in the oxide-metal systems, either at room temperature or at elevated temperatures, until data become available from the fundamental studies now in progress or yet to be undertaken.

Of considerable practical and theoretical interest is the reason for the marked decrease in ductility with increasing temperature and time at temperature exhibited by the Al-Al_2O_3 products as well as by the Cu-Al_2O_3 and Ni-Al_2O_3 products.

Orowan[31] has stated that, at maximum deformation, the slip band spacing is inversely proportional to the stress and is independent of temperature.

Experimental studies by Yamaguchi[32] and Servi and Grant[33] have confirmed this hypothesis. Accordingly, if for pure aluminum the minimum slip band spacing should be about 1 to 10 μ for stresses of 20,000 to 5,000 psi, respectively,[33] it is obvious that the size of the starting aluminum powder (50 pct with one dimension less than $\frac{1}{2}$ μ for SAP) as well as the interparticle spacing of 0.35 to 2.2 μ for the alloy are equal to or less than the slip band spacing for normally observable slip. With increasing temperature and the use of lower stresses, difficulty would therefore be expected in realizing the operation of normal slip because of the blocking effects of the Al_2O_3 particles, with a resultant drop in ductility with increasing temperature.

Efforts to utilize alloys instead of pure metal have been made by Irmann,[34] who substituted an age hardenable powder matrix for the usual pure aluminum to produce a 10 pct Al_2O_3 SAP product. Definite aging response was found using aging treatments common for the wrought aging alloy of the same composition. However, as soon as overaging temperatures were reached in testing, the higher strength and hardness of the alloyed SAP decreased to the same or lower values than those of the unalloyed SAP product, in this case above 200°C.

Principles of Alloy Development

Specification of the details of alloy systems of this type must await the outcome of these same fundamental studies. Some of the general principles governing the production of these materials may, how-

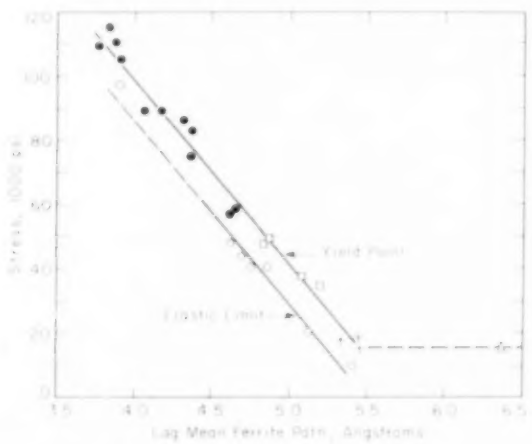


Fig. 9—Stress vs log mean free ferrite path between carbide particles in iron and various carbon steels.[35] Circle refers to spheroidite (1070 and 10100); square, ferrite-pearlite (1045 and 1020); cross, Puron; and triangle, high purity iron (National Research).

Fig. 10—Electron micrograph of SAP containing 13 pct Al_2O_3. X20,000. Reduced approximately 15 pct for reproduction.

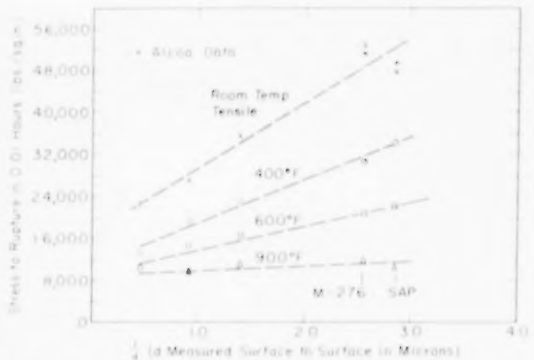


Fig. 11—Stress vs reciprocal of average spacing between oxide particles in Al-Al_2O_3 alloys for room temperature tensile strength and 0.01 hr rupture life at 400°, 600°, and 900°F.

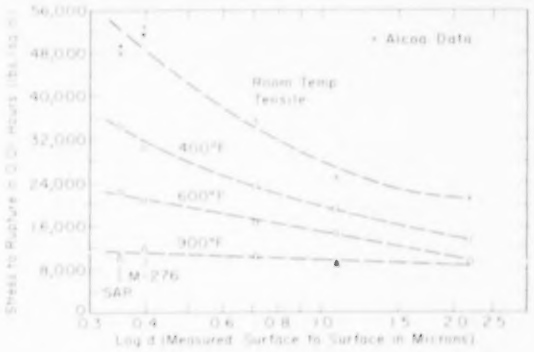


Fig. 12—Stress vs logarithm of average spacing between oxide particles in Al-Al_2O_3 alloys for room temperature tensile strength and 0.01 hr rupture life at 400°, 600°, and 900°F.

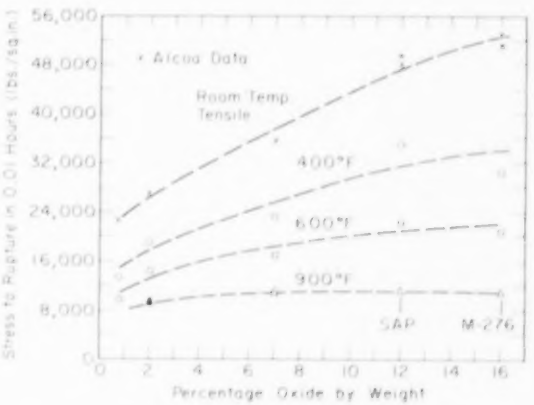


Fig. 13—Stress vs weight percent of oxide for room temperature tensile strength and 0.01 hr rupture life at 400°, 600°, and 900°F for various Al-Al_2O_3 alloys.

ever, be outlined at the present stage of development.

Mott[7] has suggested that the ideal material for resistance to creep is one of very fine grain size, with the grain boundaries filled with a phase which adheres sufficiently strongly to the grain to inhibit the grain-boundary diffusion of dislocations. He proposes that this is the mechanism responsible for the excellent high-temperature properties in SAP. Data presented above, however, do not yet indicate that adherence between the matrix and hard phase are necessary.

The most important consideration in developing a system of this type is the means of obtaining the necessary degree of dispersion of the minor phase. The change in solid solubility with temperature, characteristic of the precipitation hardening alloys, would appear to offer the most convenient and effective means of accomplishing this to yield superior properties for room temperature and relatively low temperature applications. The precipitation systems, however, suffer overaging, agglomeration, and finally resolution, as the temperature or time is progressively increased. The more stable phases such as the oxides, on the other hand, are correspondingly more difficult to form in the necessary state of dispersion. The techniques of powder metallurgy offer the most suitable means for obtaining a dispersion of a stable phase.

In the problem of the production of oxide-metal aggregates through the use of powder metallurgy, either by surface oxidation of the original metal powder, by mechanical or chemical methods of deposition of oxide on the metal powder particles, or by subsequent diffusion treatment of mixed alloy powders, as discussed briefly above, the following considerations become important: 1) the intrinsic properties of the metal which constitutes the matrix; 2) the shape and size of the metal powder particles and of the hard particle, and their relationships to each other; 3) the type and amount of the dispersed phase and its properties in relation to the matrix metal; and 4) the steps in the production of the final aggregate body from the constituent powders.

The properties of the matrix metal are determined to a certain extent by the temperature and environment of the anticipated service. Consideration must be given to the melting point and recrystallization range of the metal, its crystallographic form, its oxidation and corrosion resistance,

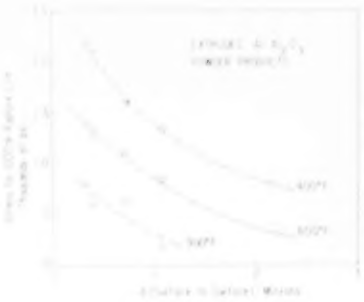


Fig. 14—Stress for 1000 hr rupture life vs average spacing between oxide particles, illustrating beneficial effects of oxide dispersion for long times at high temperature.

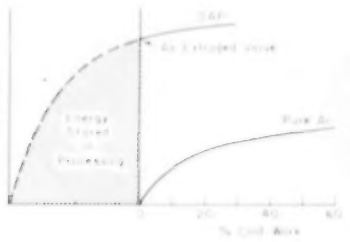


Fig. 15—Schematic representation of hardness changes with cold work in SAP and pure aluminum.

its availability in suitable powder form, and suitability for handling by powder metallurgy methods.

The shape and size of the metal powder particles in most instances directly determine the degree of dispersion obtainable in the final product. Since a very fine dispersion is indicated for the attainment of significant increases in strength, the metal powder must usually be very fine. This introduces the problem of high cost of powder, and rather expensive and difficult handling problems, which make the overall cost an important consideration for these materials.

The type of dispersed phase must be considered in relation to the matrix metal. For elevated-temperature service the minor phase should show either no or extremely limited solubility or other thermal instability in contact with the matrix. In this respect the oxides with high heat of formation have been found suitable in many systems. The deformation and fracture characteristics and mechanical strength of the dispersed phase influence the properties of the aggregate in a manner that is not yet completely understood. There are indications that quantity and size of the dispersed particles necessary for attainment of optimum properties in the aggregate vary with testing temperature. The possibility of wetting or bonding of the minor phase with the matrix metal must also be considered. This brings into consideration the possibility of treatment of the dispersed phase prior to mixing to enhance wetting on bonding properties.

The various processing steps employed to produce the final aggregate have a marked effect on the properties of the material obtained. After incorporation of the oxide phase, the materials are compacted, sintered, then hot worked (preferably by extrusion). Care is necessary in deposition or mixing of the minor phase since the uniformity of the final dispersion and with it the properties of the aggregate are strongly influenced by the effectiveness of the blending operation. More extensive knowledge is urgently needed on mixing of the hard phase with the metal powders when important differences in size, shape and density exist. Avoidance of segregation during mixing is especially important. Recent efforts to produce metallic deposited layers on the hard phase offer great hope for uniform, non-segregable composite powders.[28] The compacting and sintering steps appear to be of relatively minor importance, being for the most part only necessary for convenience in handling of the material for the subsequent hot working. Very little overall densification of the compacted material has been observed during the solid state sintering operation. The very low porosities typical of these materials are developed as a consequence of the hot extrusion, which is considered to be the most important operation in its effects on the final properties attained in the oxide-metal systems. Along with the densification of the material, the extremely high degree of plastic flow of the aggregate during the extrusion operation produces considerable rearrangement and improvement or worsening in the dispersion of the minor phase.

Additional work must also be done to study the extrusion characteristics of sintered and unsintered powder compacts composed of a mixture of a soft, relatively coarse metallic powder containing a much finer hard particle distributed in the soft matrix.

Table III. Hardness Changes in SAP After Cold Work and Annealing

Condition	Hardness, Rc
As extruded	84
20 pct cold reduction in area	86
29 pct cold reduction in area	87 (maximum cold work possible)
29 pct cold work, 20 hr at 1140°F	86
29 pct cold work, 124 hr at 1140°F	84

Work is in progress in a number of the oxide-metal systems, including some of the more refractory metals and alloys such as nickel and Ni-20 pct Cr, and more fundamental studies are being made in some systems, including the Al-Al_2O_3 alloys.

Acknowledgments

The authors are especially grateful to the Wright Air Development Center, whose support of research in this type of alloy has permitted the writing of this paper, and has stimulated thought in these very interesting alloy systems.

References

[1] R. Irmann: *Metallurgia*, 1952, vol. 46, No. 275, pp. 125–133.
[2] Sintered Aluminium Powder. *Metal Industry*, 1952, vol. 81, pp. 143–146.
[3] J. P. Lyle: *Metal Progress*, 1952, vol. 62, No. 6, pp. 109–112.
[4] E. Gregory and N. J. Grant: *Iron Age*, 1952, vol. 170, No. 21, pp. 69–73.
[5] E. Gregory and N. J. Grant: *AIME Trans.*, 1954, vol. 200, pp. 247–252; JOURNAL OF METALS, February 1954.
[6] K. M. Zwilsky: Private communication.
[7] W. S. Cremers: Private communication.
[8] W. L. Bruckart, C. M. Craighead, and R. I. Jaffee: WADC Technical Report No. 54-398, Battelle Memorial Institute, January 1955.
[9] J. Wulff: Private communication.
[10] C. S. Smith: *Mining and Metallurgy*, 1930, vol. 11, p. 213.
[11] J. L. Meijering and M. J. Druyvesteyn: *Philips Research Reports*, 1947, vol. 2, No. 81, p. 260.
[12] J. J. deJong: *Ingenieur*, 1952, vol. 64, p. O.92.
[13] J. W. Martin and G. C. Smith: *Journal* Inst. of Metals, 1955, vol. 83, pp. 417–420.
[14] E. Gregory and G. C. Smith: *Journal* Inst. of Metals, 1956, vol. 85, p. 81.
[15] R. S. Busk and T. E. Leontis: *AIME Trans.*, 1950, vol. 188, pp. 297–306; JOURNAL OF METALS, February 1950.
[16] A. B. Middleton, L. B. Pfeil, and E. C. Rhodes: *Journal* Inst. of Metals, 1948–1949, vol. 75, pp. 595–608.
[17] B. H. Alexander and R. Balluffi: Report No. NYO-663, Atomic Energy Commission, New York, 1950.
[18] A. H. Geisler: Precipitation from Solid Solutions of Metals. *Phase Transformation in Solids*. John Wiley & Sons, New York, 1951.
[19] N. F. Mott: *Imperfections in Nearly Perfect Crystals*. John Wiley & Sons, New York, 1952.
[20] E. Orowan: Discussion, *Symposium on Internal Stresses in Metals and Alloys*. Monograph and Report Series No. 5, p. 451. Institute of Metals, London, 1948.

[31] J. C. Fisher, E. W. Hart, and R. H. Pry: *Acta Metallurgica*, 1953, vol. 1, p. 336.
[32] M. Gensamer et al.: *ASM Trans.*, 1942, vol. 30, p. 983.
[33] E. Gregory: Ph. D. Thesis, University of Cambridge, England, 1951.
[34] J. Gurland and J. T. Norton: *AIME Trans.*, 1952, vol. 194, pp. 1051-1056; JOURNAL OF METALS, October 1952.
[35] E. Orowan, J. F. Nye, and W. J. Cairns: Theoretical Research Report No. 16/45, Ministry of Supply, London, 1944.
[36] N. F. Mott: *Philosophical Magazine*, 1953, vol. 44, p. 742.
[37] Current research, Battelle Memorial Institute.
[38] H. C. Chang and N. J. Grant: *AIME Trans.*, 1952, vol. 194, p. 619; JOURNAL OF METALS, June 1952.
[39] W. A. Wood and W. A. Rachinger: *Journal* Inst. of Metals, 1948, vol. 75, p. 571.
[40] J. Greenspan: Private communication.
[41] E. Orowan: *Nature*, 1941, vol. 147, p. 452.
[42] K. Yamaguchi: *Scientific Papers of the Institute of Physical and Chemical Research*, Tokyo, 1928, vol. 8, p. 289.
[43] I. Servi and N. J. Grant: *AIME Trans.*, 1951, vol. 191, p. 917; JOURNAL OF METALS, October 1951.
[44] R. Irmann: Symposium on Powder Metallurgy, Iron and Steel Institute, London, 1954.
[45] F. V. Lenel, A. B. Backensto, Jr., and M. V. Rose: Properties of Aluminum Powders and of Extrusions Reduced From Them, *AIME Trans.*, 1957, vol. 209, pp. 124-130; JOURNAL OF METALS, January 1957.
[46] Sherritt-Gordon Co.: Private communication.
[47] C. S. Roberts, R. C. Carruthers, and B. L. Averbach: *ASM Trans.*, 1952, vol. 44, p. 1150.

Discussion of the Powder Metallurgy Symposium

Chairman: F. V. Lenel, Professor of Metallurgical Engineering at Rensselaer Polytechnic Institute, Troy, N. Y.

Atkinson *(Westinghouse Electric Corp., Pittsburgh)*—May we hear your comments on the possible similarity between SAP and thoriated tungsten?

Grant—They are similar types of products. There is very definite evidence of restriction of grain growth—evidence of strengthening similar to that for molybdenum alloys where the oxide phase gets to rest at grain boundaries.

Atkinson—Is there a difference between what you have observed on high creep rate of thoriated tungsten as opposed to SAP.

Grant—Yes, but the amount of thorium added is small in relation to SAP, which has a far greater amount of oxide.

Bruckart *(Universal Cyclops Steel Corp., Bridgeville, Pa.)*—Why do you think that dispersions, particularly in molybdenum, are necessarily located at the grain boundaries. Our own work showed that this is not the case.

Grant—The only thing we have noted is that there is a marked restriction on grain growth. You would not expect the effect to occur if oxides are in the grain—they must be in the grain boundary rather than in the grain. So the conclusion must be that it is not in the grain itself.

Bruckart—I think you are right on this, but the point I wanted to make is that even in melting, the dispersions have not agglomerated and are still random. One other point: Did you note that dispersions do effect the grain growth of molybdenum?

Grant—One would have to go to exceedingly high temperatures to obtain a proper measure; but in the case of copper, where we could go to the melting point, the restriction on grain growth was clearly evident to be a large effect.

Bruckart—Do you have any information to show the effects of the combination of dispersiveness in an alloy whose strength would ordinarily be derived from the strength of the alloy?

Grant—Not enough to be sure of it. To the best of my knowledge, such studies have not yet been made. Thus far, aside from the addition of oxides to pure metals, we have studied only the added benefits, if any, of cold work after extrusion.

Bruckart—Normally when one makes an alloy there is an optimum combination of solution and cold work. This can be removed by annealing. When you make dispersion strengthened alloys, could combined benefit be obtained? Does the dispersion act equally effectively in an alloy?

Grant—We do not have an answer now, but we are studying the 80 Ni-20 Cr system to determine if further benefits can be achieved. We believe that they will be.

Smith *(LaSalle Steel Corp., Chicago)*—Is any work being done on measuring resistance to wear of these materials?

Grant—Only indirectly. I have sent out small samples to people interested in wear characteristics. We assume there will be some benefits, considering what happens to tools in machining these alloys.

Cochardt *(Westinghouse Electric Corp., Pittsburgh)*—What is the reason for the high temperature stability of SAP? Is the improvement due to the high dissociation energy of the oxide, the low solubility of the oxygen, the low diffusivity, or the high hardness of the oxide particles?

Grant—Without having done too much work in this regard, it seems that in the case of the ageing systems the change is due to change in solubility with temperature. In the case of SAP, while solubility may change with temperature, the solubility change is so exceedingly small for Al_2O_3 that the structure remains fixed. We believe that low solubility is necessary; a high dissociation energy is also vital; hardness of the excess phase is of smaller importance.

Preston—It is primarily a matter of solubility of oxygen in the matrix metal.

From the floor—I wonder if you could tell what the effect was on properties such as conductivity?

Preston—We have measured electrical conductivity of copper with 10 pct Al_2O_3. The effect of the dispersed phase is approximately the arithmetic average. In the case of 10 pct Al alloy, we have 90 pct of the conductivity of pure copper, but the drop in conductivity may

be down to 80 pct in other instances possibly due to the strained (cold worked) condition of the extruded alloy.

Atkinson—Has there been any effect on residual resistance—or have you made these measurements in the hot, extruded plus annealed condition?

Grant—In the particular cases where resistivity was measured, we could not really anneal the material. Resistivity remained pretty much constant since we had not recrystallized the Cu-Al_2O_3 alloy by reheating up to 800°C.

Atkinson—In other words, resistivity is pretty much the same in the extruded material as in the annealed?

Grant—Yes, provided that the structure does not recrystallize or soften, as is true of SAP.

Bruckart—I have been thinking of the possible answer to Atkinson's question regarding thoriated tungsten. We combined a number of oxides in one molybdenum alloy. As a result of comparing its behavior with others, it fell into the class of those considered to be ineffective, and in most cases a microscopic examination of the structure revealed that oxides were strung out in the alloy. This is a direct indication that the oxides were very soft at the working temperature. Most effective were oxides of the transition elements. Most ineffective were oxides of the alkali and alkaline earth metals.

It seems there are a number of differences in behavior between SAP and precipitation hardened type alloys. For instance, it is hard to anneal SAP and have low hardness whereas in conventional precipitation hardened systems, softening is easy to accomplish and the work hardening function is not significantly disturbed.

Gregory *(Sintercast Corp of America, Yonkers, N. Y.)*—Concerning the effect of oxide additions on recrystallization. I did some work some time ago on silver containing alumina dispersions made by the internal oxidation of silver-aluminum alloys. One example shows clearly how these phases can inhibit recrystallization, and then when recrystallization is finally achieved how the disperse phase can inhibit grain growth.

A single crystal of Ag-0.25 pct Al, produced in a vacuum furnace, was oxidized throughout at 850°C, cold rolled and then heated in oxygen at 800°C for 20 hr. There were no visible signs of recrystallization. A further heating for ½ hr at 930°C in oxygen caused recrystallization to start, but the grains after annealing for 20 hr at this temperature were still only a few microns in diameter.

The importance of hot working on the properties of SAP has been mentioned. In this connection the effect of extrusion variables such as extrusion ratio, temperature, and speed are of interest. The effect of these on powdered magnesium products have been shown by Brown of the Magnesium Elektron Company in England. It is reasonable to suppose that similar effects should be found with SAP.

Stanley *(Crucible Steel Co., Pittsburgh)*—Is there any data to indicate how properties relate to direction of extrusion?

Lenel *(Rensselear Polytechnic Institute, Troy, N. Y.)*—We have extruded strip from aluminum powder which was tested both in the direction of extrusion and perpendicular to it. We found that the strength was the same in both directions.

Grant—That was the case for Professor Lenel's Al-Al_2O_3 alloys, and also for SAP, wherein measurements by X-rays showed only a small preferred orientation; but in an Al-2 pct Al_2O_3 alloy, Gregory and Grant measured a rather severe preferred orientation. In our Cu-Al_2O_3 alloys, orientation effects were severe according to microstructural evidence, and we would expect large differences in properties in the transverse direction. Better mixing would of course diminish these defects of structure.

From the floor—How about ductility?

Lenel—Ductility was the same in both directions.

From the floor—The test results point out that a major drawback of SAP is its high tensile notch sensitivity. That bothers designers.

Grant—This material (SAP) still follows many of the same type of rules that ordinary materials do. We ran notch stress rupture tests at 600° and 400°F; at 400°F where we had 6 to 8 pct elongation in short time tests, the material was not notch sensitive. In tests lasting from 200 to 400 hr, ductility had fallen to less than 5 pct. Under these conditions the alloy was notch sensitive.

At 600°F, we found notch sensitivity set in at a more rapid rate. These are the results obtained with SAP. On the other hand, one thing to keep in a mind is that these Al-Al_2O_3 compositions constitute a series of alloys each of which has a different combination of properties. If we had taken 4 pct oxide alloy we would have had a much more ductile alloy which would have shown different and improved notch sensitivity.

Hirsch *(General Electric Co., Schenectady, N. Y.)*—During the past several years we have had the occasion to extrude many metal powders; we did not make SAP, but with other alloy systems found that 100 to 300 mesh powders could produce strong, fully dense bodies, superior to products made from cast metals. I ascribed these improvements in part to the oxide films around each particle and the resultant grain size. I felt that now the powder metallurgist need no longer bow to the conventional metallurgist when it came to considerations of the mechanical properties of metals.

Gatti *(General Electric Co., Schenectady, N. Y.)*—Could Professor Grant describe stress-strain curves at high temperatures?

Grant—We performed a number of tensile tests on the Cu-Al_2O_3 alloys at room temperature only. A rather interesting behavior resulted: the stress-strain curves showed two yield regions, one near 10,000 psi, and another near 30,000 psi. This behavior was the direct result of using —200 mesh copper powder. The first region of yielding was that due to pure copper, with attendant work hardening of these coarse copper islands. The second yield was the yielding of the aggregate. In the Al-Al_2O_3 alloys, such as SAP, the stress-strain curve was normal, because of the more homogeneous structure.

Gatti—Could you describe the flow characteristics at high temperatures?

Grant—The creep curves appear normal. We have not run high temperature tensile tests. We have not yet been able to resolve the structure of these alloys to determine the nature of the deformation which takes place.

Preston—Along with creep, we measured modulus, by dynamic means, at temperature. It was unfortunate that we had copper, because anisotropy of modulus in copper masked the modulus effect. Where we had high copper content, we had high modulus because of the anisotropy, with values as high as 20 million psi in low oxide materials and 14 million to 16 million psi for high oxide. Whether this is due entirely to anisotropy is hard to say; it is unfortunate that we did not use an isotropic material such as aluminum.

Lenel—I want to emphasize a point Prof. Grant made. The properties of extruded material vary widely depending on the degree of dispersion of the second phase. In aluminum powder extrusions, this degree of

dispersion can be varied by varying the average thickness of the aluminum flake powder particles which are extruded. Extrusions made from powder with an average thickness of 0.17 μ have a tensile strength both at room temperature and at 750°F of nearly twice that of extrusions from a powder with an 0.8 μ average flake thickness. On the other hand, the extrusions from coarse powder are more ductile than those from fine powder. The extrusions are also quite different with regard to preferred orientation, which is very pronounced in the extrusions made of coarse powder, but almost absent in the one made of fine powder. Finally the extrusions differ with respect to the case of recrystallization after cold work. Commercial Swiss SAP extrusions, which are made from powder with quite thin flake thickness, cannot be recrystallized after cold working, even when they are heated to just below the melting point.

Extrusions from coarser flake powder can be recrystallized after cold working although the recrystallization temperature is much higher than for ordinary wrought aluminum. This phenomenon is being further investigated and, we hope, will lead to a further clarification of the strengthening mechanism in SAP. Another way to improve our understanding of the strengthening mechanism in despersion strengthened materials would be to investigate the relationship between degree of dispersion and the mechanical and physical properties in materials other than with an aluminum base.

Busk *(Dow Chemical Co., Midland, Mich.)*—With respect to stability at high temperatures for long times, we see the same effects in magnesium. If hot work is combined with annealing, the stability is much decreased. Is this also true with SAP?

Grant—I don't know what Dr. Lenel's experience has been, but our work indicates that one cannot get much cold work into SAP. Hot work could be carried out readily, without apparent loss of properties. Annealing did not diminish the properties after hot or cold work in the case of SAP. Was your work done with oxides or other hard phases?

Busk—Both. I assume it might depend on the material added.

Lenel—In aluminum powder extrusions prepared in the laboratory in which the time of extrusion, and therefore the time during which the material is subjected to high stresses at elevated temperatures, is very short, the particles of the aluminum oxide appear platelike under the electron microscope; in other words, in the same shape as they were as oxide skins on the original particles. When these experimental extrusions are examined after repeated working and annealing and also when commercial extrusions which are subjected to high stresses at elevated temperatures for long times are examined, the shape of the oxide particles appears to be more or less spherical. This is an indication that particles change their shape under conditions of commercial extrusion. It should be emphasized however, that extrusions with such spherical particles dispersed in a matrix have still quite high strength.

Cochardt—It is important to have a small particle size of the matrix powder in the case of mechanical mixtures. However, this is not true if you use internal oxidation—as long as the diffusion times do not become excessive.

Hirsch—The concept of internal oxidation is indeed clever but it has its limitations, too. For it to work, one element of the system must have much greater susceptibility to oxidation than any of the other elements. The more universal solution is to disperse a finely divided oxide throughout any chosen metal matrix. For such a system to succeed, both the oxide (or any other hardening phase) and metal must be extremely fine and intimately mixed.

Grant—It is too expensive to get less than 1 μ powder. It is easier to get better particle dispersion and fineness by internal oxidation.

Gregory—It is true that internal oxidation has its limitations. It must be borne in mind that this method is only suitable for the introduction of small oxide percentages in certain limited matrix materials. However, due to the very fine dispersions which can be obtained by internal oxidation, these low percentages may be as effective as larger percentages introduced by other methods.

Hirsch—A major difficulty of the internal oxidation method is the slow rate of oxygen diffusion and, therefore, the slow treatment of thick, dense bodies. Would it not be possible to prepare the material in the form of a porous mass, internally oxidizing the material taking advantage of the pores for ready access of the oxygen and, subsequently, consolidating the body with pressure and heat?

Grant—This isn't a bad idea. Much of the work in the past has been done with dense materials. I visualize that one will be able to get 10 μ powders in a wide variety of compositions in the near future. I don't believe that diffusion through —10 μ particles will be difficult to control. You might get a sintering effect that would cause some difficulty. In our own work we are using mechanical mixing now and hope to use internal oxidation much more extensively.

From the floor—Speaking still in terms of powder particles of internally oxidized materials, an additional factor to keep in mind is that the powder particle surface must be clean enough to get good bonding so oxides will do some good. I noticed all the oxides are melted. Did you have an oxide that actually melted?

Preston: In some studies we have worked with copper wherein a film of cuprous oxide was formed; the product was then compacted, sintered, and extruded. While the oxide was not liquid, it was quite plastic at the extrusion temperature. Under these conditions we obtained a uniform dispersion of cuprous oxide, elongated in the matrix. They were small, discrete particles with 5 to 10 length to diameter ratio.

Properties obtained at 250°-450°C in creep rupture indicated that some gain was found at 450°. The properties obtained were lower than for pure copper at 250°C. What would the structure look like? Similar to wrought iron, with the cuprous oxide readily resolvable at 500X.

Lesznyski *(Schwarzkopf Development Corp., New York, N. Y.)*—A few years ago Seitz gave data on diffusion measurements of several metals into SAP and pure aluminum. The interesting result was that, in general, these elements diffused faster in SAP than in pure aluminum. I wonder if the same thing was observed in copper?

Grant—We have not made similar studies as yet, but one might expect that diffusion in SAP would be higher due to the very much finer grain size.

Webber *(Clevite Corp., Cleveland)*—Are these particles of Al_2O_3 in your copper and aluminum bonded to the matrix? We know in the case of SAP, that the Al_2O_3 is bonded to the matrix phase, and Lenel said this morning that when Linde B alumina was added to atomized aluminum there was no increase in strength even though oxide content was increased. My question is: Is there any evidence of bonding in your work?

Preston—We have at present no evidence that there is any bonding in the case of the alumina-copper system. This work was all performed in the solid state. This of course does not rule out the possibility of bonding or wetting, but we have no evidence and no measure of bonding between the Al_2O_3 and copper, and do not expect any to exist.

It seems in the case of Al_2O_3-aluminum that the attraction between the aluminum and the oxygen atom would be considered quite a strong bond. In the case of the copper matrix and Al_2O_3, the bond is probably non-existant. If there is bonding in the system, it is by no means as important as in SAP.

The high strength increases which we have observed in the Cu-Al_2O_3 alloys tends to indicate that bonding between oxides and metal may not be too important, or necessary.

Hamblin *(Westinghouse Electric Corp., Pittsburgh)*—Can you tell us the oxide content in the molybdenum experiments?

Grant—I understand these molybdenum powders were of high purity, 0.001 to 0.002 pct O at most. The refractory oxide additions were of the order of 1 pct or less in most instances.

Hirsch—I would like to know if it is essential for the oxide to be coherent with or wetted by the matrix metal if the maximum strength of a composite body is to be developed.

Grant—An absolute answer can't be given at this time; however in the case of Cu-Al_2O_3 alloys which were sintered in hydrogen, there is little reason to expect wetting between copper and Al_2O_3, yet significant gains in both low and high temperature strength were achieved.

These results were repeated with copper-silica and also with copper-copper oxide, and in all instances there was some gain in mechanical properties. But we are not yet in a position to rationalize these gains to the extent of saying that there is not a contributory effect to strength due to wetting. My personal feeling is that on the basis of existing theories and experimental evidence, I would say you don't need wetting to get a strong material.

Technical Note

X-Ray Microscopy of As-Grown and Deformed Single Crystals of Aluminum

by J. H. Auld, R. A. Coyle, A. M. Marshall, and N. A. McKinnon

IN making a study of the slip deformation and strain hardening of single crystals of aluminum, it has been found that considerable information additional to that provided by the usual metallographic techniques can be obtained by the use of the microfocus X-ray method described by Schulz.[1] This technique has been applied to crystals both in the state *as-grown* by the strain-anneal method and after they have been subjected to increasing amounts of plastic strain. Kelly and Wei[2] have recently reported the use of this method for a study of lineage structure in aluminum single crystals grown from the melt.

The crystals, prepared from aluminum of 99.99 pct purity supplied by British Aluminium Co. Ltd., were grown in the form of flat tensile specimens with a gage section of 0.3 by 0.1 in. and a gage length of 2.3 in. The microfocus X-ray tube used provided a focus of approximately 50 μ half width.

Examination of a large number of as-grown crystals showed no sign of any macroscopic defects in the majority of cases. However, occasionally crystals grown by the strain-anneal method did show defects similar in nature to those shown by Kelly and Wei to occur in crystals grown from the melt. In some other cases a more regular appearance of black and white lines, corresponding to valleys and ridges, respectively, in the lattice, was obtained, Fig. 1. This particular crystal was slightly deformed as the lines when present in the image of an *as-grown* crystal are only barely visible. The angle of tilt of the blocks is of the order of 3'. It seems likely that these tilt boundaries arise during the growth of the crystal due to the specimen not being perfectly flat on the hearth of the furnace and straightening under its own weight at the elevated temperatures.

Fig. 1—Single crystal of high purity aluminum. White lines correspond to ridges in the lattice. X3.

For the deformation studies the crystals were strained in a Polanyi-type tensile machine. A typical photograph taken after 1.2 pct elongation of a single crystal oriented with its axis fairly close to the center of the stereographic triangle is given in Fig. 2. The reflection, which is from the {111} planes, is traversed by two systems of parallel lines. These have been identified as traces of the primary (111) slip plane and the (110) plane perpendicular to the primary slip direction.

The latter lines correspond to kink bands which could not be detected by the ordinary techniques of

J. H. AULD, R. A. COYLE, A. M. MARSHALL, and N. A. MCKINNON are with the Aeronautical Research Laboratories, Melbourne, Australia.

TN 381E. Manuscript, July 31, 1956.

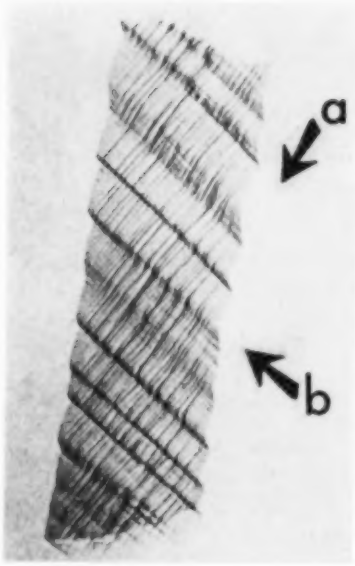


Fig. 2—Image from a deformed crystal shows a) bands parallel to the primary slip bands and b) kink bands. Blackening corresponds to high X-ray intensity. X3.

optical microscopy at this small amount of plastic strain. However, the subsequent application of a modified phase contrast method confirmed the presence of kink bands in the positions indicated by the X-ray micrograph. The change in orientation across a kink band is shown by the displacement of the edge of the image at the kink band. This change is of the order of $\frac{3}{4}°$ in this case.

With regard to the lines parallel to the primary slip lines, bands of secondary slip[3] were observed optically and a count of these gave approximate agreement with the number of lines seen in the X-ray image. The operation of a second slip system would cause these regions to have a slight localized orientation change and thus produce markings in the X-ray images. Using a straight knife edge as a reference line across the incident beam enabled orientation changes for these lines of up to 27' to be measured.

Acknowledgments

The authors thank R. I. Garrod for his helpful advice throughout this work and the Chief Scientist, Department of Supply, Australia, for permission to publish this note.

References

[1] L. G. Schulz: *AIME Trans.*, 1954, vol. 200, p. 1082; JOURNAL OF METALS, September 1954.

[2] A. Kelly and C. T. Wei: *AIME Trans.*, 1955, vol. 203, p. 1041; JOURNAL OF METALS, September 1955.

[3] R. W. K. Honeycombe: *Journal Institute of Metals*, 1951–1952, vol. 80, p. 45.

Cominco's New Sinter Plant

A lead smelter treating a high proportion of hydrometallurgical zinc plant residues requires specialized technique of feed preparation to incorporate the residues with other feed into a pelletized form for sintering. The design and operation of such a plant at Trail, B. C., is described.

by E. A. Mitchell, J. F. Melvin, and R. Bainbridge

IN the fall of 1953, The Consolidated Mining and Smelting Co. of Canada Ltd. put into operation a completely new and modern plant for sintering the rather complex assortment of materials which comprise the feed to the Lead Smelter at Trail, British Columbia. This Lead Smelter is one section of an integrated metallurgical plant producing lead, zinc, silver, gold, cadmium and other metals. Since most of the incoming lead concentrate contains appreciable zinc values, and most of the zinc concentrate similarly contains appreciable lead values, the cross-routing of residues or tails from the respective lead and zinc plants offers obvious advantages in recovery of metals, and has been practiced for many years. A disparity has existed, however, between the output of zinc plant residue and the capacity of the Lead Smelter to treat it, with the result that over the years a stock-pile of residue had been accumulating, and by the end of World War II had reached the formidable total of half a million tons.

To treat this stock-pile, in addition to all current zinc plant residues and, of course, the regular quota of lead concentrates, became a prime objective of the Lead Smelter following World War II. As zinc plant residue plays an important part in the operations to be discussed in this paper, some consideration of its

E. A. MITCHELL, Member AIME, J. F. MELVIN, and R. BAINBRIDGE, Member AIME, are, respectively, Superintendent, Smelting Dept.; Plant Superintendent, Sintering Plant; and Assistant Superintendent of Development, Smelting and Refining Depts., Metallurgical Div., The Consolidated Mining and Smelting Co. of Canada Ltd., Trail, B. C., Canada.

TP 4393D. Manuscript, May 16, 1956. Pacific Northwest Regional Conference, Seattle, May 1956.

properties is in order. Cominco has two types of this residue to deal with; one from the acid leaching of the regular zinc calcine (roasted concentrate), and one from the acid leaching of zinc oxide fume produced by retreatment of smelter blast furnace slag. The latter residue is the smaller portion of the current make, at 120 to 160 dry tons per day and, being rich in lead, is never stocked. In both cases the residue is produced as a wet filter cake which is either pumped or trammed in *V* cars to its destination. The calcine leach residue, which is the major portion, at about 360 tons per day, contains from 32 to 35 pct moisture as produced. Any which is ponded gradually *sets up* as it air-dries to about 20 pct moisture, forming a fairly firm mass which can be reclaimed with power shovels and trucks. Metal content of the stock-pile material runs about 22 pct Zn and 11 pct Pb.

During the years immediately prior to World War II, a technique of sinter plant feed preparation had been developed whereby the zinc plant residue was premixed with the dry ingredients of the sinter charge, and the mixture dried to the correct moisture content for sintering. (This step has become known as the *wet-mix* step and the term will be used in this sense in what follows.) A pilot mixing and drying plant had been built, but the installed drying capacity was not adequate to treat the daily output of residue from the zinc operations. The old sinter plant, moreover, dated back to the early nineteen hundreds and was not only inadequate tonnage-wise but was in very poor mechanical condition.

With this background, preliminary study of the problems involved in modernizing and enlarging the sintering operation was begun. Such factors as the correct integration of the proposed new plant with the other metallurgical operations, space limitations, and the general arrangement of equipment were given careful consideration. It was recognized that the main problems to be faced in designing a new plant were fundamentally mechanical, not metallurgical, and involved the handling of large tonnages of material—solid, liquid and gaseous.

After numerous arrangements had been drawn up and studied, a final design was developed which appeared to answer all the requirements. A scale model of the proposed new plant was built and submitted to careful scrutiny before being finally modified and accepted as the approved design, see Fig. 1.

The following sections of this paper will outline some of the more pertinent data which served as a basis of plant design and will discuss plant operation subsequent to erection from both a metallurgical and mechanical standpoint.

Plant Design

Production and metallurgy required that the new plant would:

1) Produce 2,000 tons of finished sinter per calendar day containing up to 500 tons of lead. Treatment rates were based on a 110-hr week.

2) Treat all current zinc plant residue and permit the reclamation of up to 250 tons per calendar day of stock-pile residues.

3) Roast in two passes, producing a finished sinter low in sulfur content and of suitable physical quality for optimum blast furnace operation.

In addition to the above, the plant design should be such that: 1) wherever possible, automatic instrumentation would control the process; 2) routine maintenance would be facilitated to the maximum degree; and 3) a high standard of industrial hygiene would be maintained through proper dust control and building design.

A plant charge, based on a reasonable forecast of future requirements, was calculated as shown in Table I.

Mixing and Drying—The purpose of the mixing and drying section is to receive the weighed dry ingredients; add a predetermined quantity of wet zinc plant residue; thoroughly mix to assure homogeneous distribution of the various components, particularly fuel; and dry the mixture to a controlled moisture content.

From the basic charge it was calculated that the production of a first pass sinter feed with an average 7 pct moisture content would require the evaporation of 283 tons of water per calendar day or 18 tons per hr for a 110-hr week. (It is to be noted that 150 dry tons per day of current zinc plant residue will have been predried to 15 pct H_2O in existing dryers and treated as dry ingredients.) Based on recommendations of various manufacturers, it was decided that three 10 x 80 ft concurrent-fired rotary dryers, each rated at 6 tons water evaporation per hr, would be installed. By referring to the basic charge again, it will be seen that the average moisture content of the first pass charge would be 18.0 pct. At such a moisture content the mixture would be a slurry and relatively free-flowing. Such a material is not suitable for efficient rotary dryer performance. Also, during drying, the mixture would pass through an extremely viscous stage which would have the effect of building up dryer crusts, creating a serious operating problem. To minimize this problem and assure the maximum dryer efficiency it was decided to recirculate sufficient dryer product to give a net water content of 11.5 to 14 pct, depending on the physical characteristics of the charge. In this moisture range it had been determined by test that the feed mixture would be crumbly. It was expected that dryer crusting would be held to a minimum and, with the material showering throughout the whole length of the dryer, fuel efficiency would be high. The material flow is illustrated by flowsheet, see Fig. 2.

In addition to the customary dryer draft indicators, a system of recorder-controllers was included in the design for this section of the plant. The purpose of this instrumentation was to control automatically 1) the rate of flow of pulverized coal to the burners to maintain the required rate of water evaporation, 2) the additions of secondary combustion air, and 3) the addition of tempering air to maintain a constant predetermined gas temperature at the dryer inlet.

Sintering—Basically, the sintering operation is one of roasting and, as in most roasting processes, oxidation takes place through the proper use of air, with the production of heat.

Experience had shown that an improperly pelletized and conditioned charge would tend to pack when layered on a standard sintering machine, throttling the passage of an adequate quantity of air for proper roasting. Although the product from a rotary dryer tends to be pelletized, the degree of pelletization can vary over a wide range, depending on such factors as moisture content of the dryer product, the relative proportion of *binding* material in the charge, and the physical characteristics of the charge components.

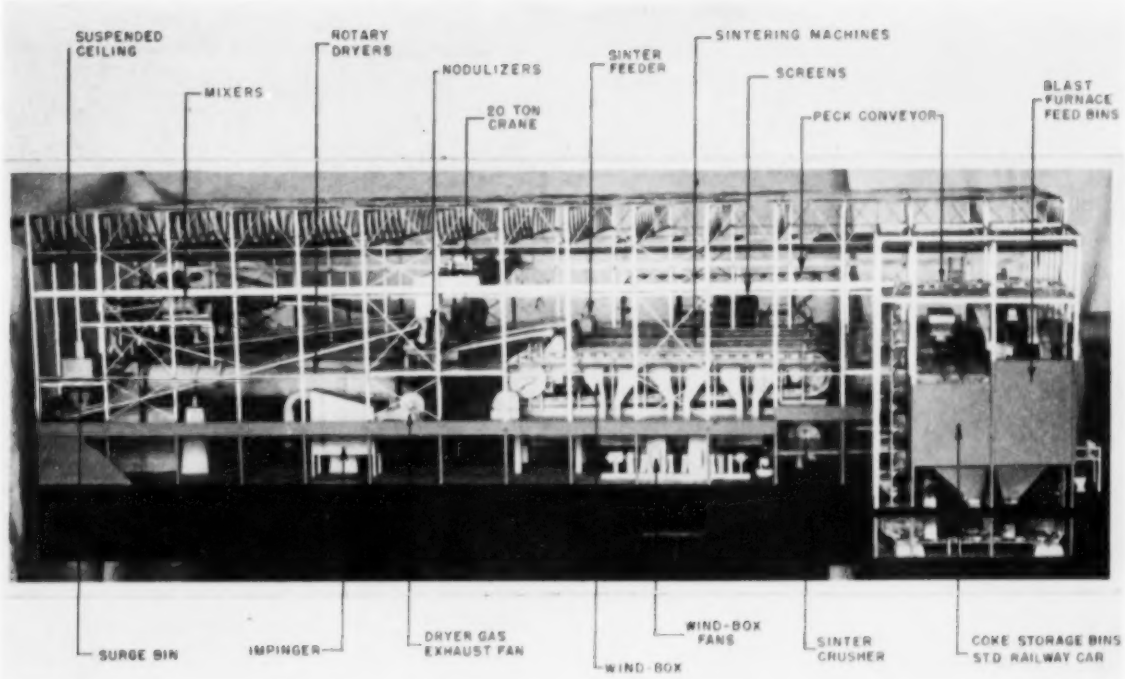


Fig. 1—Photograph of model of new sintering plant, showing general arrangement of equipment. The roof structure with a suspended ceiling is particularly noteworthy.

To minimize variations in the texture of the roaster feed, a pelletizer was provided ahead of each sintering machine. These pelletizers were simple rotating rubber-lined drums, 9 ft diam by 16 ft long. Since the degree of pelletization of any feed mixture could vary with the peripheral speed of the drum and the retention time, the pelletizers were designed for variable speed and adjustable slope.

Sinter Machine Design, Windbox Area: The grate capacity was determined by experience and test to be 0.21 tons of sinter per hr (net) per sq ft of windbox area on first-pass and 0.095 tons overall. Hence the basic charge tonnage in a 110-hr week would require 554 sq ft of windbox grate area for first pass and 787 for second.

After weighing the merits and disadvantages of few large machines vs numerous small machines, the decision was for the former. Three machines 10 ft wide were finally chosen, each with 630 sq ft of windbox area, one of which could act as spare for either first or second-over.

Fan Equipment: Test data and plant experience had shown that the requisite air volume for satisfactory sintering was: 1) for first pass, 65 cfm (stp) per sq ft of windbox area at the grates or, allowing 25 pct leakage, 81 cfm (stp) at the fan, and 2) for second pass, 90 cfm (stp) per sq ft of windbox area or 113 cfm (stp) at the fan.

To determine true volumes at operating conditions which would serve as a basis for fan design, average plant data were utilized. These are illustrated graphically in Fig. 3. This graph portrays air volume, the percentage of SO_2, and the gas temperature prevailing as roasting proceeds. It will be noted that gas temperatures are high and SO_2 concentrations relatively low toward the end of the roasting time indicated. It was recognized that, ideally, a series of fans should be installed along the length of each machine, each being controlled separately through a series of windboxes. This was deemed impractical. As a compromise it was decided to divide the windbox area into six equal sections and install two fans, one handling the rich gas from the first four windboxes and the second, the gases from the last two. This arrangement would make it possible, if it were required at some future date, to recirculate the weaker gas and so produce a gas of higher SO_2 concentration.

Based on predicted gas temperatures and volumes, and in consultation with fan manufacturers, fan specifications were drawn up as in Table II.

For the preliminary design, fan speed control through the fluid drive would be based on draft at the fan inlets. Since the gas would be relatively wet (dew point estimated at 135°F), and of relatively high SO_2 content, all fan casings and windbox ducts would be of mild steel construction, but heavily insulated. Fan runners would be stainless steel.

No attempt was made at this time to design a new flue and humidification equipment to condition the gas for dust recovery in the existing Cottrell precipitator. The old flue system would be used until such time as gas data were confirmed by operation.

Sinter Machine Design, General: Generally speaking, the machine design followed the normal Dwight-Lloyd (straight-line) pattern. However, certain modifications were incorporated. Because of the size, it was decided that the loaded pallets, when discharging, should not be allowed to run free from the top. A discharge sprocket, controlled by a brake, was provided at the discharge end of the machine to release the loaded pallets at the bottom. This would permit a bump adequate to remove the sinter cake without damaging impact.

Another feature of the sintering machine design worthy of note is the method of removing windbox

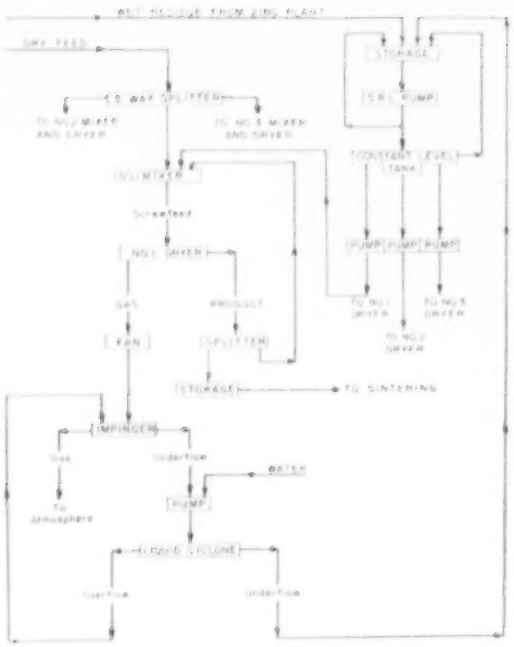


Fig. 2—Schematic flow sheet of mixing and drying.

cleanings. Those familiar with a lead-bearing charge know the problem involved in removing metallic lead from a dry windbox. A wet windbox will produce a granulated product but its removal from six 10 x 10 ft windboxes presented a challenge. The final design included a continuous 9 ft 7 in. wide rubber belt conveyor. This belt ran within the water windboxes and close to the bottom, discharging any cleanings into a boot at the end of the machine. An inclined drag conveyor was provided to remove this material continuously from the boot. A general arrangement of the new machine is illustrated in Fig. 4. A flowsheet of the sintering section is shown in Fig. 5.

Instrumentation: In the sintering process, there are certain key data which, properly interpreted, will indicate such factors as degree and rate of roasting, gas volumes and, indirectly, physical quality of final sinter. A centrally located control room was designed from which all the plant, with the exception of the sinter crushing section, is visible. All control instruments and recorders were located in this room. Each sintering machine had its own instrument panel. Instruments included in the design were: 1) SO_2 recorders on each fan, 2) draft recorders on each fan, 3) indicating ammeters on each fan motor, 4) six point temperature recorders on each machine to show individual windbox temperatures, and 5) machine speed indicators with push-button control.

In addition to the above, recording instruments were provided for such general information as main flue temperature, draft at certain key locations, SO_2 concentration at the absorption plant, plant air pressure, etc.

Sinter Crushing Plant—In a sintering operation where sulfur is to be removed in two passes the first pass roast must be crushed to as fine a product as is practical without actually pulverizing. This exposes the residual sulfides tied up in the first pass material and permits further sulfur removal in the second and final roasting operation.

From basic charge data it is evident that 116 tons per hr of first pass sinter had to be crushed exclusive of any recirculation. Added to this would be some 15 to 20 tons per hr of fines (−¾ in. material) screened out of the final sinter and returned to the first-pass sinter conveyors. For the proposed crushing plant flow sheet, see Fig. 6.

Allowing a circulating load of 100 to 125 pct the following plant requirements were outlined: 1) two sets of 54 x 24 in. smooth rolls, operating at 1,250 ft per min; 2) roll drive, 50 hp individual drive for each roll shell; 3) roll setting, 3/16 in.; 4) screening area, not less than 50 sq ft per roll; 5) screen, double deck Ty Rock or other similar type, with throw in direction of flow; 6) screen cloth, standard or medium light Ty-Rod with 0.250 in. opening on bottom deck; 7) theoretical capacity, 72 tons per hr; 8) screens and rolls to be close-circuited by a pivoted bucket elevator conveyor; 9) to allow for surges and return sinter on first pass charge, it was considered that the load to be handled by the pivoted bucket elevator might be as high as 400 tons per hr and, therefore, a 36 x 36 in. conveyor should be installed; and 10) to prevent vibration from the rolls carrying through to other parts of the building, particularly the instrument control room, the rolls would be mounted on oak blocks on an *island* free of the main building structure.

General Aspects of Plant Design—A design requirement that was given careful consideration and observed wherever possible was ready access to all equipment, particularly the heavy equipment, for maintenance purposes. The main building was designed to accommodate a 40-ton crane which would have this access. Equipment was located to provide

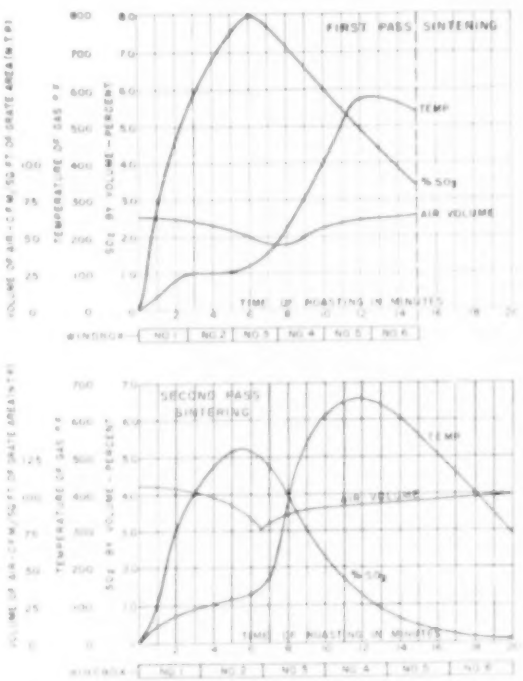


Fig. 3—Graphs indicating the normal relationship between percentage of SO_2 gas temperature, and air volume vs roasting time.

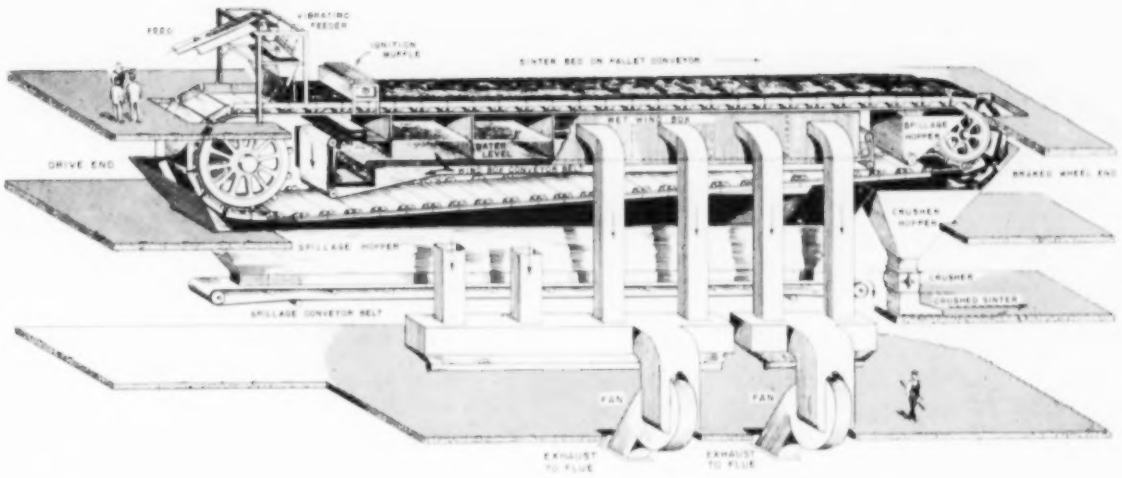


Fig. 4—Pictorial diagram of sintering machine

adequate working space. A standard gage railroad track was run into the building so that heavy equipment could be transferred to the main repair shops if and when required. Truck access was provided on two levels. Floor space was reserved for a repair shop section where routine maintenance could be handled.

The importance of industrial hygiene was stressed in all phases of the plant design. Lead-bearing dusts and fumes being toxic, all conveyors were hooded, and all points of material transfer were designed to minimize plugging and were ventilated, as was any operating equipment which might produce dust. The application of a wet scrubber* to this service was carried through to completion. This equipment, built in several standard sizes, was installed throughout the plant to collect and recover the ventilated dusts. Building design provided for a suspended roof and for all structural steel to be imbedded in concrete where possible, to avoid ledges on which dust could accumulate.

* The Doyle scrubber, developed by Cominco, available through Dorr-Oliver in the United States and through Power-Gas Canada Ltd. in Canada.

Another section of the plant was designed to store final sinter, blast furnace coke, and other miscellaneous materials on blast furnace charge, and to proportion them out as required. However, discussion of this section will not be included here.

Construction of the new plant took place in stages, with the section comprising the sinter machines and crushing equipment in full scale operation by October 1953. The drying and feed preparation section, housed in the same building, was completed one year later.

In general, the plant has proven its potential capacity of 2,000 tons of sinter per day. Current requirements of 1,700 tons per day allow for the treatment of a relatively greater proportion of wet residues and for more down time. The somewhat altered feed program from that postulated when the original plant design was worked out has necessitated some changes in the equipment. Comments on these will be included in the remaining portion of the paper, which deals with operation.

Plant Operation

A fairly detailed description of the equipment in the new plant has been published,[1] and in this paper only as much of this ground will be retraced as is necessary for clarity and continuity in the present account.

Proportioning of the concentrates, fluxes, reclaimed dump residues, conditioned flue dusts, fuels and other materials on charge is carried out in the old section of the plant, where reconstruction has not yet started. There are 17 primary charge bins having a total capacity of 26,000 cu ft. The bins are in line and are accessible only by narrow gage tramming. Each bin has two 30 in. discharge feeder belts which are driven through clutches from three separate line shafts. Bin gates are adjustable and weights checked by a weigh bucket suspended on a monorail. A long conveying system transports this material to the new wet-mix plant. Here a mechanical feed splitter proportions the feed evenly to as many of the three dryers as are operating.

Current zinc plant residue at 33 to 35 pct moisture is pumped 1,700 ft from the zinc plant and is received in two 100-ton storage tanks. To maintain this residue as a homogeneous slurry, continuous circulation is provided by a 3 x 3 in. SRL pump which moves the material from the bottom of the tanks to constant head boxes at the top level of the plant. From these head boxes the required amount of slimes for each dryer is drawn by adjustable-stroke diaphragm pumps, and the excess returns by launder to the storage tanks. The heavy (specific gravity 2.1 to 2.3) and viscous nature of the slimes requires close coupling of the diaphragm pumps to the head boxes to maintain the required flow and to achieve reasonably accurate control of delivery. Small discharge boxes on each pump allow frequent checking of volume and density.

It has already been mentioned in considering design requirements that the normal charge of dry materials, when mixed with the planned quota of current residues, would produce a mixture containing some 18 pct moisture. Such a mixture, it was realized, would not be suitable as a feed to the dryers. It would, in drying, pass through a sticky

Table I. Basic Sinter Plant Tonnage Data

	Dry Wt Tons per Calendar Day	H_2O, Pct	Wet Wt Tons per Calendar Day	Pb, Tons per Calendar Day	Zn, Tons per Calendar Day	S, Tons per Calendar Day	H_2O, Tons per Calendar Day	Wet Wt Tons per Hr, 110 Hr Wk
Dry Components of First Charge								
Sullivan lead concentrates	389	9	428	248	31	71	39	27.2
Cardin concentrates	265	6	283	129	20	45	18	18.0
Other Cominco concentrates	33	3	36	21	2	6	3	2.3
Iron concentrates	120	9	132	1	1	42	12	8.4
Siliceous ores	155	2	158	—	—	—	3	10.0
Limerock	180	1	182	—	—	—	2	11.6
Stock, zinc plant residue	150	15	176	18	33	10	26	11.2
Dried zinc plant residue	115	15	136	12	26	7	21	8.7
Total	1,407	—	1,531	429	113	181	124	97.4
Wet Components of First Charge								
Zinc plant residue, calcine leach	360	34	546	38	82	24	186	34.6
Zinc plant residue, fume leach	160	42	276	48*	16	14	116	17.6
Total	520	—	822	86	98	38	302	52.2
Mixed feed	1,927	18	2,353	—	—	219	426	149.6
Dryer product, net	1,927	7	2,070	—	—	—	143	132.0
Water to evaporate	—	—	—	—	—	—	283	18.0
Circulating load at 7 pct to produce 13 pct H_2O feed	1,840	7	1,970	—	—	—	—	125.0
Second Pass Feed								
First pass sinter	1,820	3	—	—	—	91	—	116.0
Granulated slag to second pass	180	—	—	5	31	—	—	—
Gypsum (binder) to second pass	100	—	—	—	—	17	—	—
Second pass total	2,100	6	2,240	472	—	108	—	142.0
Second pass sinter	2,000	—	—	—	—	24	—	122.0

* Circulating load.

stage before reaching a crumbling stage, and severe crusting of the dryers would be a certainty. To overcome this, provision was made to recirculate dryer product sufficient to reduce the average moisture content of the feed to the range 11.5 to 14 pct. Experience since operations commenced has shown that even this was too wet and that the proper range is 10 to 12 pct. The recirculation needed to attain this is some 500 pct, and the load through each dryer is between 225 and 250 tons per hr. This high load proved too much for the original system of premixing the slimes and dry feed in a double-shafted paddle blade mixer and delivering the aggregate to the dryer by an inclined screw feeder. The mixers and feed screws were supplanted by 36 in. feed belts and chutes for solid material, and the metered slime routed directly by 4 in. pipe line into the top end of the dryers. Sufficient mixing takes place in the first few feet to absorb the slimes before they contact the shell of the dryer, and crusting is not now a problem. Two shell rappers at the feed end of each dryer provide further aid in keeping crusting to a minimum. These are steel disks 16½ in. diam, weighing about 160 lb each, riding in a frame on top of the dryer, and running on a stepped flat-bar track welded to the dryer shell. The disks have a free drop of 5½ in., and strike six times in every revolution of the dryer.

The 10 x 80 ft dryers are driven by 250 hp motors through *V*-belt drives to reduction gear units and mechanical clutches. They turn at 4 rpm and have a slope of ½ in. per ft. The heavy live load introduced a serious spillage problem at the feed end, which was largely corrected by altering the lifter arrangement to provide faster take-away. The lifter arrangement is now as follows: in the top 3 ft of length, six equispaced spiral lifters 10 in. high set at 45°; in the next 16 feet, six at 8 in. and set at 30°; in the next 50 ft, seven sections each having 12 lifters 10 in. high by 8 ft long, set parallel to the dryer axis and staggered with respect to adjoining sections. The last 11 ft have no lifters.

Firing of the dryers is concurrent and is by powdered coal flame, the fire boxes having a design capacity of 1 ton of coal per hr. Actual normal operating rate has been 1.1 ton per hr. Average dryer capacity is 6 tons of water removed per dryer hour. The gases at 350°F are exhausted by 175 hp double-inlet fans to Doyle scrubbers, where practically all of the entrained values are removed. The scrubbers discharge the gas to a flue tunnel and thence to a plywood stack. The effluent from the scrubbers is treated in 8 in. liquid cyclones. Cyclone underflow at 30 pct solids is added to the plant slimes circuit while the overflow recirculates continuously to the scrubbers.

The product from each dryer is conveyed by a short 30 in. belt to a long 24 in. inclined belt which returns it to a point above the feed chute to the dryer inlet. A two-way splitter permits separation of the required fraction of product, and the major portion returns to the dryer circuit. A 50-ton surge bin levels out minor disparities between wet-mix plant production and sinter machine requirements.

Dryer Product Control—As is well known, the proper preparation of the sinter feed is of the utmost importance to good sintering metallurgy. Close control of the physical properties of the dryer product is maintained by frequent moisture analysis. For this purpose a *Speedy Moisture Analyser* has proven invaluable, giving dependable moisture determinations in less than 10 min. Optimum moisture varies with the nature of the charge, being about 7.5 pct on high-lead charges and as high as 9.5 pct on low-lead high residue charges.

First Pass Feed Preparation—Although the dried feed is partially pelletized by the rolling action of the wet-mix dryers, further preparation is decidedly necessary and is provided by the pelletizers ahead of the sinter machines. These 9 x 16 ft cylindrical rubber-lined drums, through the rolling action they induce in the feed pellets, serve both to harden them and to incorporate on their surface some of the fines which come through in the feed. Water or plant slimes are added in discreet amounts to the pelletizers when necessary to adjust the moisture content upward for best sintering. Retention time in the pelletizers at present is about 1½ min and indications are that up to 4 min would be beneficial.

Zinc plant residue is a satisfactory *binder* for the formation of a pellet product when mixed with concentrates and fluxes. For low-concentrate high-

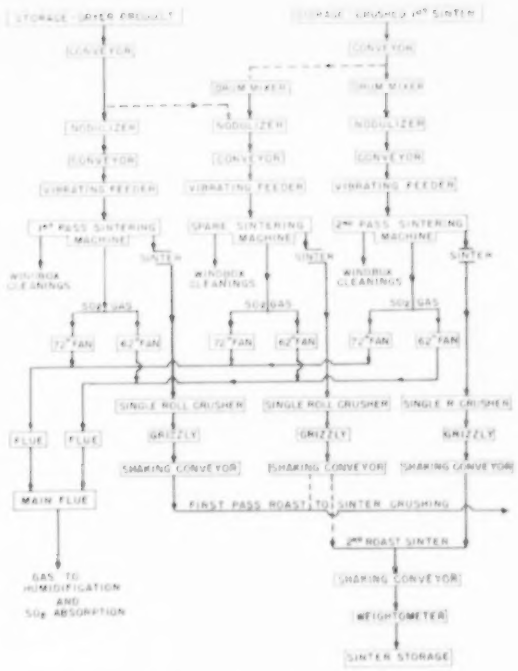


Fig. 5—Schematic flow sheet of sintering process.

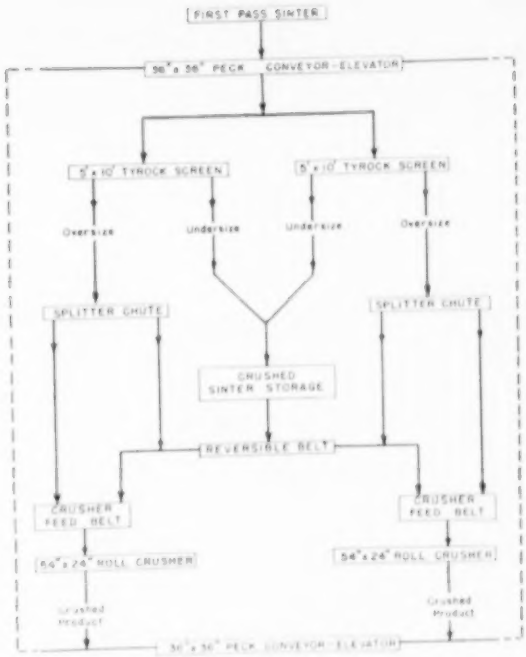


Fig. 6—Schematic flow sheet of sinter crushing.

residue charges, pellet formation is no problem, although conditioning is still necessary. For high-concentrate mixtures (over 38 pct Pb), some additional binding effect can be obtained by the use of gypsum in place of limerock flux in the charge mixture. Gypsum in large quantities is available as a by-product from Cominco's nearby phosphoric acid plant. Its use for this purpose is attractive or otherwise, depending on whether the cost of reclaiming dump gypsum or dewatering current gypsum, plus the cost of additional fuel for decomposition, is offset by limerock saving and value of additional sulfur evolved.

Fuel in the form of coke breeze is added to the feed if the sulfur content is below about 10 pct. For present operation, with sulfur running from 8.5 to 9 pct, the breeze requirement is about 1 pct of the charge. For a high concentrate charge with much over 10 pct S, more than enough fuel is present and the practice is to recirculate enough of the crushed first sinter to maintain sulfur at 10 pct.

First Pass Sintering—As indicated in the first portion of the paper, three sinter machines were provided, identical except for capacity of the exhaust fans. Windbox size is 10 ft wide by 63 ft long; overall length of each machine is 107 ft and they are set parallel at 36 ft centers. One serves for first pass roasting, another for second pass, and the center unit is a spare for either.

The pelletized product is conveyed by belt to a vibrating deck distributor at the feed end of each sinter machine. Even distribution of the pelletized feed across the width of the pallets is one of the problems inherent in the design of large sintering units. The obvious and tried methods such as swinging belts, table feeders, etc., which have stood the test of time in narrower machines, are not so readily applied to the greater width of present day design. At any rate, for Cominco's installation the space savings offered by vibrating deck feeders looked attractive in the design stages, and such feeders seemed in plant tests to offer few operating or maintenance problems. Experience has not confirmed these findings unreservedly. With the best of feeder performance the feed is well spread and gently bedded on the grates behind the levelling hopper, but all too frequently the feed sticks to the vibrator decks and builds up, requiring periodic shutdowns for cleaning. The interruptions are, of course, unsatisfactory both for drying and sintering. Performance on second pass feed is considerably better than on first, due to the harder, less sticky nature of the feed. The remedy may lie in better pelletization of the dryer product in the first-over pelletizers, either by longer retention as is planned, or possibly by flame hardening.

Ignition equipment is a brick muffle supported by water-cooled beams above the pallets. Opposing oil burners fire across the bed from each end. Oil consumption ranges from 0.72 Imperial gallons per ton of sinter on high concentrate charges to 0.92 on high residue charges.

A sinter bed depth of 9½ in. is standard practice and allows adequate volumes at low drafts to ensure fast sintering rates. Typical data are presented showing volumes, temperatures and drafts, Fig. 7. It should be noted that sintering time is sometimes cut to a minimum so that there may be a small band of incompletely roasted material left.

The roasted sinter is quenched by water sprays over the discharge end dead plate. Adjustment of the sprays to give a dust-free product which is not too wet for subsequent handling requires careful hand control by an operator. The sinter discharges from the dump end of the machine into a hopper above a 9 ft wide single-roll crusher set at 3½ to 4 in., with the breaker plates held in position by 4 x 6 in. wooden blocks. The coarsely crushed sinter falls

Table II. Fan Specifications

Fan	Duty	Cfm	Temperature, °F	Standard Pressure, WG	Fan, Rpm	Fan, Bhp	Fluid Drive, Bhp	Elevation, Ft
No. 1, first pass roast, windboxes 1 to 4*	Peak	62,000	426	20	1,055	266	296	
	Normal	47,500	217	20	910	210	271	1,530
No. 2, first pass roast, windboxes 5 and 6†	Peak	39,000	655	20	1,340	175	182	
	Normal	28,400	355	20	1,123	132	164	1,530
No. 1, second pass roast and spare machine, windboxes 1 to 4‡	Peak	117,000	750	20	1,310	567	591	
	Normal	87,500	436	20	1,102	408	495	1,530
No. 2, second pass roast and spare machine, windboxes 5 and 6§	Peak	68,000	940	20	1,552	306	319	
	Normal	52,000	617	20	1,348	232	273	1,530

* No. 72 in. FH, DI, DW type MD sintering fan with type SCR4, size 26 fluid drive and 350 hp motor.
† No. 62 in. FH, DI, DW type MD sintering fan with type SCR4, size 23 fluid drive and 250 hp motor.
‡ No. 72 in. FH, DI, DW type MD sintering fan with type SCR4, size 29 fluid drive and 650 hp motor.
§ No. 62 in. FH, DI, DW type MD sintering fan with type SCR4, size 26 fluid drive and 350 hp motor.

through the rolls directly to shaker conveyors, and thence to the crushing plant. The conveyors are used for both first-pass and finished sinter, and will be discussed later.

First Sinter Crushing—Fig. 6 shows the schematic flow sheet, much as it is now, except that the interconnecting of the two sets of screens and rolls has been found unnecessary and two cross conveyors have been eliminated. Experience has taught the need of carefully designed cast iron chute liners. Either of the parallel systems can carry 70 pct of the full plant tonnage. Bottom deck screens combine one $\frac{3}{8}$ in. and two $\frac{1}{4}$ in. Ty-Rod openings.

Of special interest is the *beading* of the roll shells. The normal roll set is between $\frac{1}{4}$ and $\frac{3}{8}$ in. The 3 to 4 in. sizing in the crusher feed material failed to nip in the rolls, causing plug-ups. A single welded bead of hard surfacing across the roll face in two opposite positions has solved this problem without any ill effects.

There is a magnet above a special stainless steel pan trough on the shaking conveyor supplying first-pass sinter feed. Most of the tramp iron is removed here. However, circulating loads of tramp iron have to be cleared by picking manually from the pivoted bucket carrier (Peck Conveyor).

The screen undersize originally discharged to rubber-lined steel hoppers and thence by conveyor to second-pass feed storage. The hopper sides were divided in three sections and inflatable canvas hose placed between the rubber and steel. Replaceable all-rubber panels are now installed and are more successful in preventing build-ups. They are poked manually at frequent intervals.

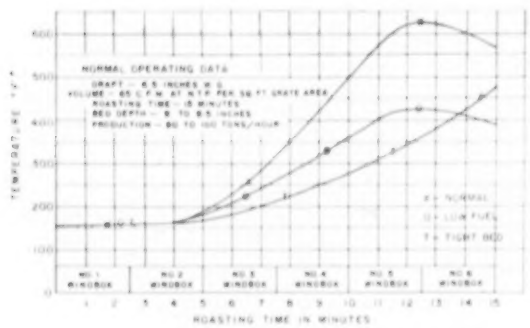


Fig. 7—First pass sintering of off-gas temperature vs time.

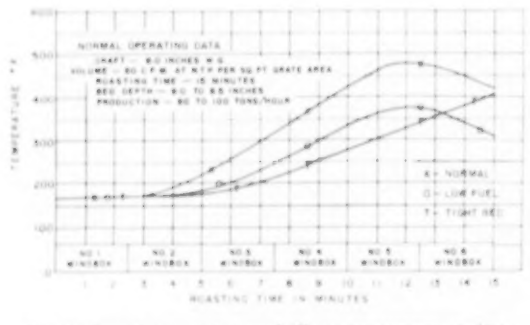


Fig. 8—Second pass sintering of off-gas temperature vs time.

Second Pass Sintering—The crushed first sinter is practically all minus $\frac{1}{4}$ in. and contains $4\frac{1}{2}$ to 5 pct total sulfur, of which only $2\frac{1}{2}$ to 3 pct is sulfide. This is too low in fuel for good sintering and the addition of up to 1 pct coke breeze has been found essential. The crushed first roast is lacking in any binder to promote pelletization, and by itself beds very tightly, roasts slowly and gives a poor quality finished sinter. Various binders are used to improve this. Among them are moistened flue dust recovered by Cottrell treater from the sinter machine smoke, thickened plant slimes from the ventilation scrubbers, and dried zinc plant residue. The roast material, coke breeze, and binder are mixed in a Stehli-type drum mixer before being pelletized with water or plant slimes in the second-over pelletizer. Enough water is added in the pelletizer to bring the moisture up to about 5 pct.

This sintering step is similar in most respects to the first-over sintering. There is a notable difference, however, in that metallic lead is formed in the hot mass and percolates down through the grates. This molten lead, for the most part, is chilled into globules or *shot* in the water bath of the windboxes, but any which adheres to the windbox separators (which are just clear of the bottom of the travelling grates) causes binding and can eventually stall the machine. The remedy for this was to water-cool the separator top plates, so that the lead chills quickly and does not adhere to the cold surface. Some typical operating data are shown in Fig. 8.

Sinter Machines—A sketch of the machines themselves is given in Fig. 4. The speed of the pallets can be varied from the control room between 2 and 6 ft per min. Depth of the bed is regulated by an adjustable talus plate at the feed end, normal depth being $9\frac{1}{2}$ in. on first stage roasting and 9 in. on second.

The individual pallets, of which there are 60 on a full machine, are illustrated in Fig. 9. This also shows the grate bar arrangement. The original herring-bone type of grate has been supplanted by

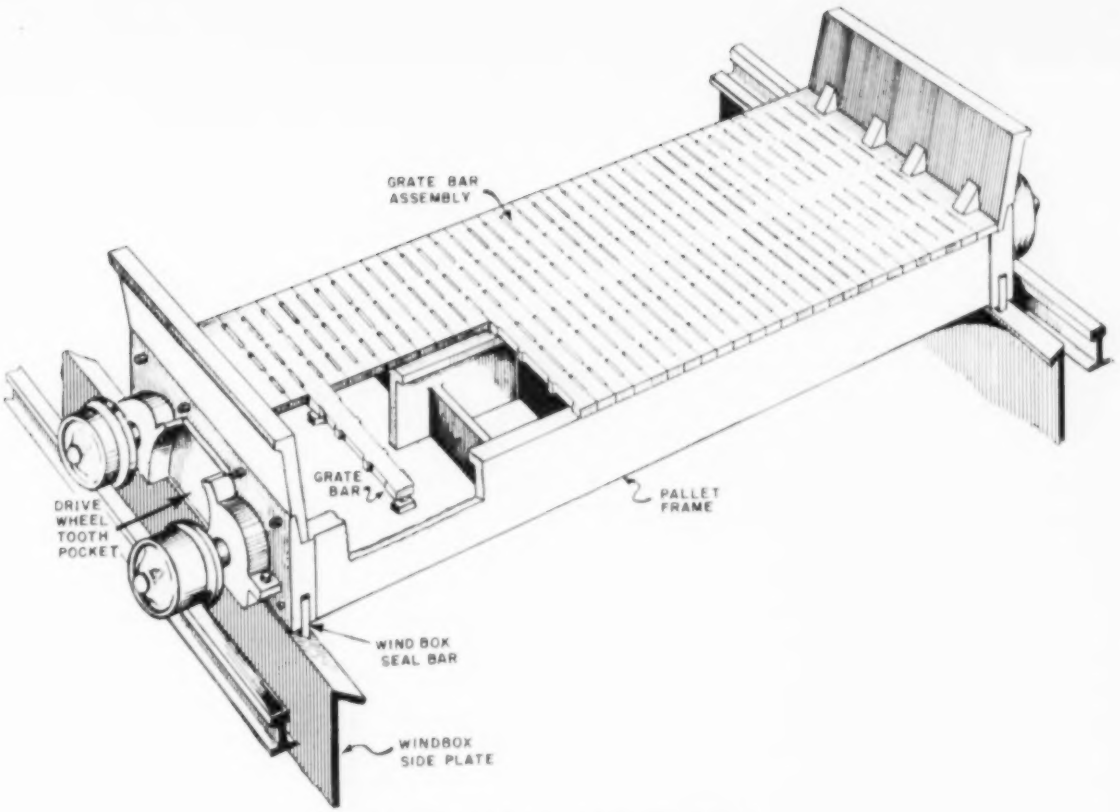


Fig. 9—Pictorial diagram of sinter machine pallet.

straight bar grates, as shown, although it is possible that use of the former may be resumed at a later date. Finger lugs at each end of the grate project under the horizontal top flanges of the longitudinal structural members of the pallet casting. The lug fit is loose, which prevents the bars from falling out on the return travel but permits ample movement between them. Double-length bars at intervals of 6 or 8 prevent the short bars from wracking sideways and falling out. Cast steel has been found superior to cast iron and is standard. Grate consumption figures have not yet been established.

The sinter which falls through the grates into the windbox water bath forms the so-called *windbox cleanings*; and in a normal day with a production of 1,700 tons of sinter the cleanings will amount to some 20 to 30 tons of first pass, and 20 tons containing much shot lead on second pass. Continuous removal of this material by the 9 ft 7 in. rubber belt is one of the prime achievements of the new machines and this improvement has been patented. A word of caution to others contemplating this procedure: keep the bearings on the belt roller shafts out of the water by carrying the shafts through glands in the side plates to outside bearings.

Corrosion of mild steel anywhere in the windbox is severe and it has been found necessary to line the boxes in their entirety with light gage stainless steel plate. Conditions are not quite so severe in the boot where the belt discharges and a protective coating of Permolite gives satisfactory protection. The flat bottom plate of the windbox requires special consideration, as the scouring action of any hard material getting under the belt (despite the fact that the make-up water is added under the belt) and being dragged over the plate by the belt movement causes abrasion and corrosion of the stainless steel. The only known answer as yet is thicker plate, and all three machines now have ½ in. stainless steel plate bottoms. Corrosion of the insulated mild steel flues and fan casings has not been a problem. Dust fallout is negligible also, and the collector screws on the bottom of the roaster fans and main collecting flues are not required.

Sinter Conveying—There are probably few conveying problems in industry more exacting than the movement of a quenched lead sinter, with individual chunks of every conceivable shape, and ranging in size from about 80 lb down to dust particles. The larger pieces still have red-hot centers and give off steam and gas for quite some time. The small sizes form a gritty mud with the excess water. A closed, vented, spill-proof conveyor with few moving parts for such a material is much to be desired. The shaker conveyors incorporated into Cominco's plant are one solution and, with further adaptation to the peculiar conditions of sinter plant service, should be satisfactory.

The first-over sinter is conveyed to the crushing section and the final sinter to the blast furnace feed section by these conveyors. Pan life of the 3/16 in. plate pans is about 120,000 tons on first-over and 100,000 tons on final sinter, with pans of abrasion-resistant steel fabricated with grain structure crosswise to direction of material flow. The stroke amplitude is 7 to 9 in. and frequency 72 to 83 strokes per

min. Drive motor hp is 20 on most units, 15 on light duty ones.

Ventilation and Plant Slime Recovery—All material dump or transfer points are vented through Doyle Scrubbers to exhaust fans and thence to plywood stacks. Ducts and scrubbers carrying heavy dust loads are attended every day. Careful design is, of course, necessary in the construction of hoods and positioning of off-take ducts.

It is of interest that *Herisite*-coated weatherproof grade plywood has stood up well for vent duct construction and has proven cheaper and more satisfactory than rubber-lined steel pipe.

The water-borne solids from the scrubbers and floor washings are carried by launders through a surge tank to six settling tanks. Settled solids are pumped to a 1,000 cu ft storage tank in the wet-mix drying plant. There solids are further dewatered in two stages with three 8-in. liquid cyclones. Original equipment provided 12 3-in. liquid cyclones. Fine particle recoveries were good enough on the 8 in. units and a simpler arrangement resulted. The large dryer scrubbers are serviced by a separate system including one 8-in. cyclone.

Labor—The crew works under the direction of a shift-boss and two assistants. On each 8-hr shift there are three men on the feed belts, six in the wet-mix plant, one in the control room, four on the sinter machines, two in the crushing plant, two on the shaking conveyor floor, one on plant slimes, one on plant clean-up and three in the flue dust section (Cottrell Treater). There are also two men on steady day shift servicing dust scrubbers and two reconditioning pallets. Services such as tramming, oilers, janitors, etc., bring the total up to about 87 per 24 hr day.

Reference

1 Canadian Mining Journal, 1954, vol. 75, p. 233.

Discussion of this paper sent (2 copies) to AIME by May 1, 1957 will appear in AIME *Transactions* Vol. 209, 1957, and in JOURNAL OF METALS, October 1957.

Comparison of Blast Furnace Penetration With Model Studies

A new correlation of the penetration of air into the blast furnace is presented, which agrees with data taken on blast furnaces at Wheeling Steel Corp. Data taken by rodding the tuyeres are examined critically and the variance between the figures at the different tuyeres is discussed.

by J. B. Wagstaff and W. H. Holman

IN spite of considerable interest among blast furnace operators on the question of the penetration of air into the furnace, there is still uncertainty as to how far the blast does, in fact, penetrate. Moreover, it is not always clear just what is meant by the word *penetration* in this sense.

In 1952, Elliott et al.[1] showed that at the end of each tuyere of a blast furnace there is more or less of a void. In this region, coke particles are blown around by the force of the air. This explained the well-known observation reported by Sweetser[2] that if a bar is pushed into a furnace through a tuyere it will go easily into the furnace a distance of some

J. B. WAGSTAFF, Member AIME, is Physicist, Research Laboratories, U. S. Steel Corp., Kearny, N. J. W. H. HOLMAN, Member AIME, is Assistant General Superintendent, Steubenville Works, Wheeling Steel Corp., Steubenville, Ohio.

TP 4427C. Manuscript, May 23, 1956. Blast Furnace, Coke Oven and Raw Materials Conference, Cincinnati, April 1956.

3 to 4 ft before coming up against a firm resistance. It is apparent that the bar penetrates across the width of the raceway before coming up against the lower part of the *deadman*. Thus the penetration of the bar corresponded approximately to the diameter of the raceway.

In 1953, Wagstaff[1] considered the subject in more detail. The raceway was shown to be approximately spherical in shape and a correlation was given for predicting the size of the raceway. This correlation was criticized by Gardner,[2] who proposed some modifications.

Following this work, two independent studies have been made. In the first, further work on models has led to an improved correlation. In the second, a large number of measurements of raceway size were made at the Steubenville plant of Wheeling Steel Corp. The data were obtained by rodding all tuyeres of each of five furnaces at frequent intervals, usually hourly. In this way, more than 3000 measurements of individual raceway sizes have become available for analysis. This report discusses and compares these two studies.

Model Studies

The earlier studies of raceways in small models had been restricted to observation of a single jet and its raceway in a model that was rectangular in plan. Since raceways seem to be about as wide as they are long, there was some question as to the applicability of the earlier work to the blast furnace that has many tuyeres arranged around the circumference of a circle so that the raceways might overlap. Experiments were therefore carried out in models shaped, in plan, like a segment of a circle, such as is shown in Fig. 1. The jets in the model were arranged so that one of them was close to the plexiglas side, and the raceway could be observed directly. It would be comparable to those reported in the earlier work. The other three jets were arranged so that the middle one was between two normally operating raceways and any interference would be the same as that in a completely cylindrical model.

Observation of this central raceway was difficult because it could not be seen through the surrounding particles. However, it was found possible to use polystyrene particles that were sufficiently transparent to allow some light to penetrate to the raceway. It was then found that the movement of particles could be observed with a closed-end glass tube. The eye could easily detect movement at the end of the tube though it was quite insensitive to the conditions along the side.

As a result of these studies, and of a further review of the earlier work, a new correlation for raceway size was obtained. It is shown in Fig. 2, in which the data have been plotted on logarithmic scales. Had linear scales been used, the points would have fallen on a straight line but much of the information would tend to bunch into the corner of a linear plot. The data cover a rather wide range of 1 to 20 on the ordinate and 1/10 to 20 on the abscissa. By using logarithmic scales, it is a little easier to see the spread of the points.

The relationship shown has been determined empirically and is considered to be the best expression so far found to correlate the large number of variables that have an influence on raceway size. Both ordinate and abscissa are dimensionless. It has been found that the technique of employing dimen-

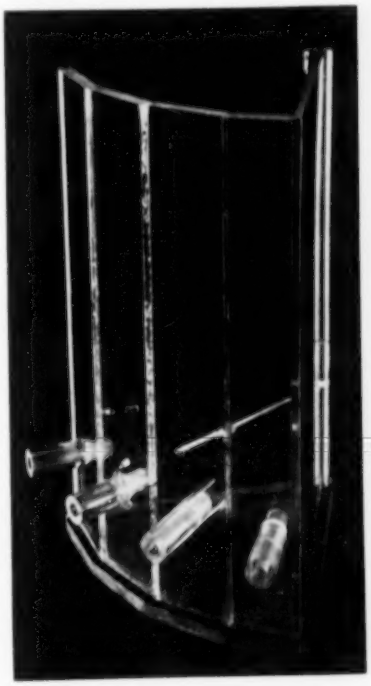


Fig. 1—Typical multiple-jet model.

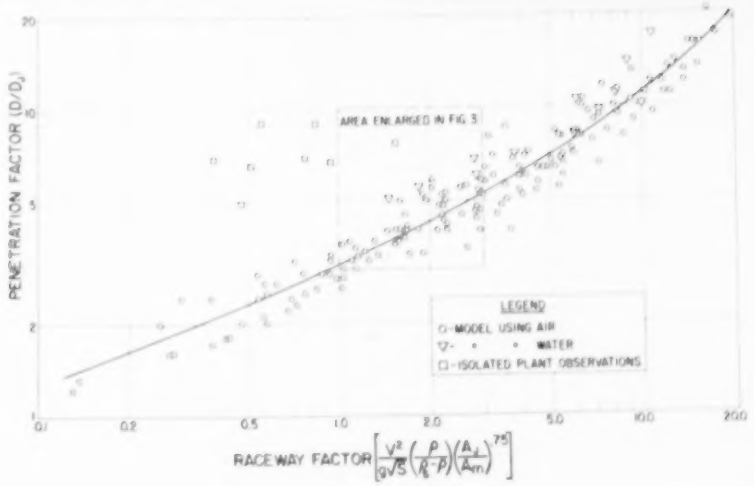


Fig. 2—Correlation of model data.

sionless ratios instead of raw numbers usually enables a wider range of information to be correlated easily. To obtain a dimensionless ratio, it is necessary to arrange variables so that the result is independent of the units employed, provided they are consistent. For example, the ordinate is the ratio of two lengths; specifically, it is the diameter of the raceway D expressed as a ratio by dividing it by the jet diameter D_j. This obviously is the same whether both tuyere and raceway are measured in feet or inches.

The abscissa, which for convenience in this report will be referred to as the raceway factor, consists of three ratios multiplied together and incorporates the main variables that control raceway size. The first ratio incorporates the linear velocity of the air in the tuyeres V in feet per second, and the size of the particles. Here, size is taken as the square root of the surface of a typical particle S expressed in square feet. The force of gravity g (ft per sq sec) is also included.

The next ratio relates the density of the air (ρ lb per cu ft) to that of the solid particles (ρ_s), in the form of the ratio $[\rho/(\rho_s - \rho)]$. The final relationship is the ratio of the total tuyere area A_t (sq ft) to the hearth area of the furnace, A_w (sq ft). The importance of this relation comes as a surprise to the authors and was found by working with a number of models of different size. Its exact significance is not known. It is known, however, that the velocity of gas up the furnace affects the flow of solid, probably by reducing the friction between the particles. It would therefore seem reasonable that the velocity of gases up the furnace might have an influence on raceway size. The ratio of gas velocity up the furnace to that in the tuyeres is the inverse of the ratio of the appropriate areas. The ratio $\frac{A_t}{A_w}$ is raised to the power 0.75. The value of this exponent is not known with accuracy and must be regarded as approximate.

The value of any empirical correlation depends to a great extent on the range of variables studied. Table I has been compiled to show the wide range of experimental conditions used in this model study. It should also be noted that the granular materials used consisted of regularly shaped particles of wood,

Table I. Range of Variables Used in Model Studies

Variable	Range
Diameter of jet, in.	¼ to 1
Gas velocity, ft per sec	50 to 500
Particle size, in.	0.06 to 0.21
ρ, lb per cu ft	0.08 to 62.4
$(\rho_s - \rho)$, lb per cu ft	9.1 to 94
A_w, sq ft	0.145 to 1.0
A_t, sq in.	0.049 to 0.785

crushed coke, gravel, or smooth plastic particles. Therefore, it would seem that reasonable confidence might be placed in the validity of the relationship. Fig. 2 also includes a few points taken on individual tuyeres at different blast furnace plants. These points, which were published earlier,[5] are not averages of all tuyeres around a furnace and hence are not as reliable as the information presented in Fig. 3. However, they do show general agreement with the model data.

Plant Studies

Since the raceways at all tuyeres were measured at Steubenville, it was possible to take an average size that should be a good estimate of the raceway produced by a particular condition in the furnace. These averages are plotted in Fig. 3, which is simply a portion of Fig. 2 to which the furnace data have been added, enlarged so that the furnace data can be more clearly seen. An idea of the variation between the readings on individual tuyeres can be obtained from Table II. These give the mean raceway size at a particular time for the different furnaces and both the variance and range of individual observations. The question of scatter is discussed more fully later in this report.

Fig. 3 shows that the agreement between furnace and model is remarkably good. The results for the different furnaces are separated somewhat, but overlap each other and the model data. Furthermore, if a linear relationship is assumed between the penetration D/D_j and the raceway factor, a line can be obtained by the usual statistical techniques for furnaces 1, 3, and 5, which best represent the data. There are not enough data on the other furnaces. These lines have been included in Fig. 3, where they appear slightly curved owing to the logarithmic scale. The lines are almost parallel and very close to the line for the model. It would therefore seem reasonable to conclude that the correlation is essentially sound, but that some other factor may have been different for the different furnaces, which is responsible for the furnaces not being identical with the model. This other factor is not known at the moment. Apparently the raceway is a function of the conditions of fluid flow and is little affected by the energy released by combustion.

The agreement between the furnace and model data is so good that the assumptions used in the calculation of the latter must be examined critically. The two principal uncertainties were the distribution of air among the tuyeres, which affects the velocity in each tuyere, and the size of the coke. The only assumption that seemed practical for the former was that of equal linear velocity in each tuyere, no matter what its size. This is probably wrong, because it was observed that in a furnace having tuyeres of two different sizes the penetration with the smaller ones was not proportionally smaller. It is also a fact that the ducting, gooseneck, blowpipe, and other equipment are the same size for all tuyeres and only the 15-in. length of the tuyere is changed. This may well fail to change the volume blown in proportion to the change in tuyere area. Therefore, the only logical assumption would seem to be that the volume of air to each tuyere was independent of the tuyere size, and this seems rather worse than the assumption used here.

The estimate of coke size presented rather a different problem. Only a few estimates of coke size in the tuyere zone are known to the authors. In an earlier report, measurements of a few coke samples were given and one of these was an estimate of a coke in the Pittsburgh area. Accordingly, for want of better information, the coke in these furnaces was assumed to be the same size as that previously reported for Eastern practice.[5]

It would seem that this correlation might be used to predict the effect of small changes of the different variables on the raceway size in the furnace. Undoubtedly the best way to do this is to plot the position of the existing conditions on Fig. 2 or Fig. 3 and deduce the effect of the proposed changes with the aid of the chart. However, this may not always be possible and, further, it may sometimes be ad-

vantageous to have a qualitative picture of the general effect of a given variable. The three variables considered here to be of most interest are the wind rate, blast temperature, and tuyere size. The first affects the linear velocity in the tuyeres V; the second affects both velocity V and density ρ. Changing tuyere size while holding constant the volume of wind blown changes velocity V, area of the jets A_j, and the diameter of the tuyere D_t on the ordinate. This makes it difficult to estimate the effect of changes in tuyere size without calculation.

Fig. 4 presents curves showing the approximate effect on raceway size of changes in the three variables discussed. It was obtained by calculation, assuming a typical set of conditions and deducing the effect of changing the particular variable being studied. In each case, all other variables are held constant except the one under study. The effect of increasing wind rate is always to increase raceway size and to somewhat the same extent in most cases. Similarly, increasing blast temperature increases raceway size but not, in general, as much as increasing blast rate.

The effect of changing tuyere size is quite unexpected and depends on the value of all the variables in the raceway factor. Fig. 4c shows the shape of the curve of raceway diameter against tuyere size. It is a curved line sloping down to a minimum and rising again so that, as tuyere size increases, raceway size diminishes, then increases again. It has been possible to examine three furnaces, of which one had an appreciable negative slope showing increasing raceway with decreasing tuyere size. The other two were operating close to the minimum point where raceway size is comparatively insensitive to tuyere size.

This peculiar effect of tuyere size seemed sufficiently interesting to study further, so two equations were developed, see Appendix, for giving, first, the slope of the curve and secondly, the tuyere diameter for minimum raceway size.

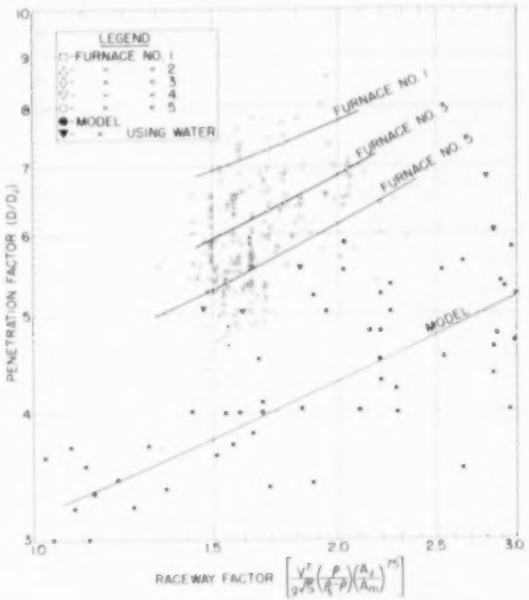


Fig. 3—Correlation of blast furnace and model data.

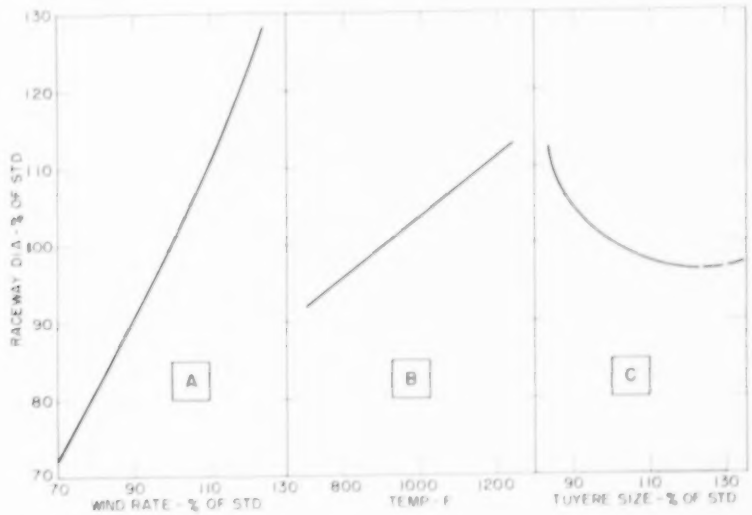


Fig. 4—Effect of operating variables on raceway diameter.

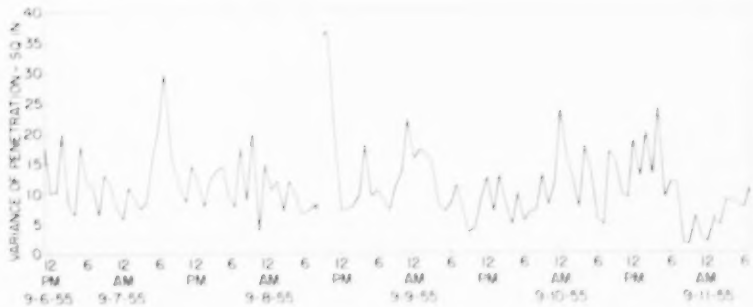


Fig. 5—Variance of penetration, furnace No. 5.

Table II. Variation in Readings

Date	Time	Wind Rate, Cfm	Temperature, °F	Pressure, Psi	Mean Penetration, In.	Variance, Sq In.	Range, In.	Remarks
				Furnace No. 1				
11/29/54	10:30 a.m.	65,000	800	17 to 18	47.45	15.52	52.5 to 44	
12/ 3/54	11:02	60,000	800	17 to 18	39.81	2.89	42 to 36.5	
	1:10 p.m.	60,000	800	17 to 18	40.50	0.61	41.5 to 38.7	
	3:15	60,000	800	17 to 18	42.15	22.57	50 to 33	
	5:15	60,000	800	17 to 18	43.17	7.33	48 to 37	
	7:15	60,000	800	17 to 18	43.12	16.28	52 to 38	
	9:15	60,000	800	17 to 18	42.83	22.33	50.5 to 36	Cast
	11:15	60,000	800	17 to 18	40.58	10.99	44 to 34	
12/ 4/54	1:15 a.m.	60,000	800	17 to 18	38.83	19.97	45 to 31	Cast
	3:15	60,000	800	17 to 18	39.75	17.66	47 to 31	
	5:15	60,000	900	17 to 18	40.42	15.17	48 to 36	Cast
	9:30	60,000	900	17 to 18	46.00	4.45	48.5 to 42	Cast
	11:30	60,000	850	17 to 18	44.95	6.47	48 to 41	
	1:00 p.m.	60,000	900	17 to 18	44.04	10.84	48 to 37	
	3:15	60,000	900	17 to 18	43.31	31.23	51.8 to 28	Cast
	5:15	60,000	850	17 to 18	43.75	20.85	49 to 33.5	
	7:15	60,000	850	17 to 18	42.77	8.06	47 to 37	
12/ 7/54	9:15 a.m.	62,000	900	17 to 18	45.41	3.44	48 to 43	
	11:30	63,000	900	17 to 18	43.23	18.38	48 to 38	
	1:00 p.m.	63,000	900	17 to 18	45.88	5.31	49 to 41.2	
					Average	13.26		
				Furnace No. 2				
12/ 7/54	9:00 p.m.	59,250	900	17 to 18	35.73	4.28	39 to 32	
	11:15	59,250	900	17 to 18	35.60	13.11	41 to 29	
12/ 8/54	1:15 a.m.	57,450	800	17 to 18	31.20	21.17	39 to 18	
	3:20	59,250	850	17 to 18	29.13	31.70	39 to 16	
	5:15	59,250	850	17 to 18	32.27	9.64	39 to 28	
	7:15	59,250	850	17 to 18	31.33	9.95	38 to 27	
	9:15	59,250	850	17 to 18	36.40	5.54	40 to 32	
	11:15	59,250	850	17 to 18	34.53	4.55	39 to 32	
	1:30 p.m.	59,250	850	17 to 18	35.67	11.81	41 to 29	
	3:45	59,250	850	17 to 18	36.27	3.17	40.5 to 34	
	6:15	59,250	850	17 to 18	33.57	20.50	42 to 29.5	
	8:15	59,250	850	17 to 18	35.07	13.64	42 to 33.5	
	10:00	59,250	850	17 to 18	36.86	18.71	42.5 to 29	
12/ 9/54	12:15 a.m.	59,250	850	17 to 18	33.70	25.24	40 to 19	
	2:30	59,250	850	17 to 18	32.80	19.10	38 to 23.5	
	5:00	59,250	800	17 to 18	30.97	25.27	37 to 21	
	8:15	59,250	800	17 to 18	33.30	7.78	38 to 27.5	
	10:20	60,500	800	17 to 18	34.43	31.82	38 to 28	
	12:10 p.m.	61,300	850	17 to 18	36.10	8.33	42 to 31	
	2:10	62,050	850	17 to 18	37.07	23.07	44 to 29	
					Average	15.41		
				Furnace No. 3				
	8:00 a.m.	53,000	850	13.5	40.13	5.87	43 to 35	Before flush
	9:00	53,000	900	13.25	37.21	14.61	43.5 to 27.5	Before flush
	10:00	53,000	900	13	38.04	10.34	43 to 31.5	Flush
	11:00	53,000	900	13	40.17	9.38	45 to 34	Before cast
	12:00	52,000	900	14	40.38	5.42	45.5 to 36	Before cast
	1:00 p.m.	53,000	900	14	38.42	8.31	43.5 to 33	Cast
	2:00	55,000	950	15	40.54	6.34	42.5 to 35.5	Before flush
	3:00	57,000	950	15	41.33	9.29	46.5 to 35.5	Before flush
	4:00	58,000	950	15	38.67	4.61	44 to 37	Before cast
	5:00	59,000	950	16	39.71	9.93	46.5 to 34	After cast
	6:00	60,000	950	16	40.00	7.95	44 to 35.5	After cast
	7:00	60,000	900	16	40.46	8.34	45 to 36	Before flush
	8:00	60,000	900	16	39.79	9.11	45 to 35	Flushing
	9:00	60,000	900	16	40.29	12.25	46.5 to 36	Before cast
	10:00	60,000	900	16	37.88	6.37	42 to 34	After cast
	11:00	60,000	900	16	40.63	7.14	43 to 35	After cast
	12:00 a.m.	59,000	900	13	36.54	6.61	41 to 33	Before cast
	2:00	59,000	900	13	37.88	4.55	41 to 33.5	Before flush
	3:00	56,000	900	13	37.75	5.43	41 to 32.5	Before cast
	4:00	59,000	900	13	34.71	12.75	40.5 to 30	After cast
	5:00	59,000	900	13	36.54	3.98	40 to 33.5	Before flush
	6:00	59,000	900	13	37.08	4.77	40.5 to 33.5	Before flush
	7:00	59,000	900	13	37.58	4.49	40 to 34.5	Before cast
	8:00	59,000	900	13	35.67	9.33	40 to 30	After cast
	9:00	51,000	900	13	34.33	3.52	38 to 32	Flushing
	10:00	52,000	900	13	34.42	8.99	40 to 30	Flushing
	11:00	53,000	900	14	36.63	2.55	39 to 34	Before cast
	12:00 (noon)	54,000	900	14	37.21	7.34	41 to 32.5	After cast
	1:00 p.m.	55,000	900	14	36.04	4.57	40 to 32.5	After cast
	2:00	55,000	900	14	37.50	11.00	44 to 33	Before flush
	3:00	55,000	800	14	37.25	1.66	39 to 36	Before flush
	4:00	55,000	900	14	37.75	4.89	43 to 35.5	Before cast
	5:00	55,000	900	14	37.13	5.82	42 to 34	Before cast
	6:00	55,000	900	15	32.38	4.73	37 to 29	After cast
	7:00	55,000	850	15	35.08	7.54	40 to 31	After cast
	8:00	55,000	800	15	34.83	8.70	39 to 31	After cast
	9:00	55,000	800	15	32.29	4.93	36 to 29	Casting
	10:00	55,000	800	15	35.04	13.75	41 to 30	After cast
	11:00	55,000	800	15	36.25	8.02	41 to 32.5	After cast
					Average	7.31		

The slope is given by the expression

$$\frac{d(D_m)}{d(D_t)} = \frac{8.49}{D_t^{1.5}} \frac{K_1}{q\sqrt{S}} \left(\frac{\rho}{\rho_m - \rho}\right) \frac{W^2}{A_m^{2.5} n^{1.5} n^{1.5}} + K_2$$

and the tuyere size for minimum penetration by

$$D_t)_{min} = \sqrt{\frac{8.49}{K_1}} \left(\frac{K_1}{q\sqrt{S}}\right) \left(\frac{\rho}{\rho_m - \rho}\right) \left(\frac{W^2}{A_m^{2.5} n^{1.5} n^{1.5}}\right)$$

where K_1 and K_2 are constants, W is the volumetric flow of air in cfm, and n is the number of tuyeres.

These expressions are rather complicated but they do serve to show that both the slope and position of the line of raceway diameter as a function of tuyere size depend on all the furnace variables. It is therefore to be expected that changing tuyere size will have a different effect in different furnaces, or even in the same furnace under different operating conditions.

An alternative explanation is that the precise value of all the different variables in the raceway factor affects the position of any particular furnace

Table II. Variation in Readings (*Continued*)

Date	Time	Wind Rate, Cfm	Temperature, °F	Pressure, Psi	Mean Penetration, In.	Variance, Sq In.	Range, In.	Remarks
				Furnace No. 4				
		60,000	900	16	41.05	16.14	47 to 36	Before cast
		60,000	900	16	40.25	11.74	46 to 35	After cast
		60,000	850	16	54.40	14.34	59 to 46.5	Before cast
		60,000	850	16	41.65	9.34	45 to 35	After cast
		60,000	850	16	41.20	21.79	49 to 34.5	Before cast
					Average	14.67		
				Furnace No. 5				
10/29/54		68,000	1000	18	32.28	18.33	44 to 25	
11/ 1/54		57,000	1000	16	21.03	4.05	25.5 to 18	
12/ 8/54		68,000	850	18	34.16	3.72	37.5 to 30.5	Before cast, 1 hr
		68,000	850	18	25.56	15.23	31.5 to 20	After cast, 1 hr
12/ 9/54		68,000	850	18	35.03	25.92	46 to 23.5	Before cast, 1 hr
		68,000	850	18	28.59	29.41	38.5 to 21	After cast, 1 hr
6/24/55	8 to 4	60,000	1050	16.25	35.57	9.65	40 to 31	
	4 to 12	60,000	1000	17	32.21	38.49	40 to 18	
6/25/55	8 to 4	60,000	1050	17	38.79	12.84	45 to 32	
	4 to 12	60,000	950	16	38.21	4.64	41 to 34	
	12 to 8	60,000	850	17	38.75	2.64	41 to 36	
6/26/55	8 to 4	58,000	1000	15	35.43	14.30	42 to 28	
	4 to 12	58,000	1000		34.64	11.48	39 to 28	
	12 to 8	58,000	900	17	34.04	12.02	39 to 28	
6/27/55	8 to 4	58,000	850	16	34.43	3.85	37 to 31	
	4 to 12	50,000	950	13	32.07	6.73	37 to 28.5	
	12 to 8	50,000	1000	14	30.89	16.31	35 to 22.5	
6/28/55	8 to 4	50,000	950	14	34.14	9.29	40 to 29	
	4 to 12	50,000	1050	15	33.36	4.09	38 to 30	
	12 to 8	50,000	1100	17	30.25	2.84	33.5 to 28	
					Average	12.48		

on the curve of raceway size against tuyere size. If it happens that a furnace is operating on the flat part of these curves, changing tuyere size will have little effect. On the other hand, if the furnace happens to be on the steep part of the curve, a change in tuyere size will have a major effect. This may explain, in part at least, why there is considerable controversy among operators about the effect of tuyere size.

Variance of Penetration

So far only the average penetration of all tuyeres at a particular time has been considered, but the variation in the data that make up these averages is of interest. This variation is best studied by calculating the variance of the readings. The variance is a well-known statistical function, which has the dimensions of the square of the dimension of the individual readings. It was found convenient to use the original penetration measurements, in inches, for this part of the investigation. Therefore, the variance is given in square inches. The variances for the readings for the different furnaces are given in Table II for furnaces 1 through 5, respectively. The average variance for each furnace is also shown. The average variance of 7.31 sq in. in furnace 3 was much less than that of the other furnaces of similar magnitude, varying from 12.6 to 15.4 sq in. Since it was reported that furnace 3 was the smoothest working furnace, with furnace 5 the roughest, there is some confirmation of the theory that the variation in the raceway size is a measure of roughness of operation.

Next, the variances were checked to see whether the changes in variance for each particular furnace could be assigned to chance alone. If not, it could reasonably be expected that there is some factor influencing the performance of the furnace that caused the differences in variation. The test is known as Bartlett's test for homogeneity. The results may be expressed as a degree of significance. An insignificant result means that the amount of difference can probably be assigned to chance alone, whereas a significant result means that probably some other factor causes the differences. It was found that only furnace 3 was insignificant, furnaces 1 and 2 were highly significant, and furnace 5 was very highly so. This checks with the observation that furnace 3 was smooth. It would seem to mean that in furnaces 1, 2, and 5 there was some variable that from time to time influenced the size of the raceway so as to make it more variable. The most obvious cause would be some minor hanging. There is reason to believe that interruptions to the smooth flow of solid can occur in such a way that the irregularities are ironed out within the stock column and do not show in the stockline movement.

Experiments with models have been carried out in the laboratory in which coke particles were fed continuously through a simulated furnace to study the solid flow condition. In these models, it was found that when a *furnace* started to become rough the raceway no longer remained the same size but increased for a time and then collapsed, only to increase again. It therefore seemed reasonable that a smooth blast furnace should be characterized by reasonably steady raceway size and a rough one by irregularities in the raceway size.

In view of this information, further data were obtained on furnace 5. This new test work covered a period of six days and probably represents the most thorough study ever made. The variance of the individual readings has been plotted in Fig. 5 as a function of time. This figure shows that the curve of variances against time was somewhat irregular, as would be expected. However, it contains some notable peaks, the first occurring at 7 a.m. on Sept. 7, 1955. At noon on Sept. 8, 1955, there seemed to be uncertainty. At midnight Sept. 8 to Sept. 9, 1955, there was another peak, which was much broader or longer in duration. It was followed by a valley, which in turn gave rise to a slow, steady rise over more than a 24-hr period, culminating in a high peak and sudden drop to the lowest point observed.

Again drawing a parallel with the model experiments, it has been observed that if the solid charged to the model contains excessive fines there is a tendency for the raceway to become irregular and the fines to accumulate in the center of the furnace. Perhaps something would change slightly and then the furnace would appear to work smoothly for a while, although the center above the deadman was not in good condition. It would not take much under these conditions to make the furnace rough again

and the condition would be cured only when the furnace hung sufficiently for the raceway to become big enough for a large amount of the *deadman* to fall when the hang collapsed. In this way, poorly sized material in the center of the furnace would be dropped and the furnace would be working much more smoothly on new material. With this background in mind, there is a question as to whether such a condition occurred in furnace 5 during the period between Sept. 6 and Sept. 11, 1955. However, there is little evidence in the pressure record of any unusual occurrences of this type. If it did occur, it is interesting to note the long period, nearly a week, over which this condition slowly developed. It would surely be of value to have some technique available for detecting it in its early stages.

After studying Fig. 5, it is not surprising to learn that the variances when tested for homogeneity were highly significant. It is most reasonable to suppose that some disturbing factor, such as a hang, was influencing the furnace at some times. It was found that this set of data was about equally inhomogeneous with that taken on furnace 5 earlier.

Summary and Conclusions

Once the model results are accepted as applicable to the blast furnace, the effect of different variables on raceway size can be calculated. Although as yet there is no evidence on the optimum raceway size, this work has shown that changing to larger tuyeres may produce a considerably smaller raceway in one case and make little or no change in another.

The agreement between the model work on raceway size with the measurements taken on the blast furnace seems remarkable. The model work is all carried out without combustion and the enormous release of energy might be expected to affect the raceway size. Possibly there is some cancellation of different effects but it would seem that the model work cannot be far wrong. This of itself is a considerable step forward.

As yet it cannot be taken as proved that there is any relation between the variance of the penetration readings and the roughness of the furnace, but this report at least raises the question. Unfortunately, the physical difficulty of taking these penetration readings probably rules out any thought of using them as a control measurement unless some mechanical means is found to take them. If some such means could be tried, it might well give useful advance information on furnace irregularities.

Appendix. Calculation of Slope of Curve of Penetration As a Function of Tuyere Size

The relation shown in Figs. 2 and 3 of D/D_t as a function of the complex term

$$\frac{V'}{g\sqrt{S}}\,\frac{\rho}{(\rho_c-\rho)}\left(\frac{A_t}{A_m}\right)^{0.5}$$

has been drawn on logarithmic scale in order to get a wide range of the variables onto a single plot. However, had the figures been drawn on rectilinear coordinates, the line representing the band of points would have been nearly straight. Therefore the following relationship will hold to a reasonable approximation

$$\frac{D}{D_t} = K_1\left(\frac{V'}{g\sqrt{S}}\right)\left(\frac{\rho}{\rho_c-\rho}\right)\left(\frac{A_t}{A_m}\right)^{0.5} + K_2 \quad [1]$$

where K_1 and K_2 are constants and the other symbols are explained in the main report. The lines shown for the furnaces were obtained by assuming that this relationship held.

Consider a case where all variables except the diameter of the tuyere D_t are held constant, except that the total volumetric wind rate is held constant rather than the linear velocity. Then the terms on the right-hand side that will vary with D are V and A_t where

$$V = \frac{W}{A_t}$$

and

$$A_t = n\frac{\pi}{4}D_t^2$$

where n is the number of tuyeres and W is the actual volumetric wind rate. Grouping all variables that are independent of D_t with K_1 to form K_3 gives

$$\frac{D}{D_t} = \frac{K_3}{D_t^{2.5}} + K_2$$

from which

$$D = \frac{K_3}{D_t^{1.5}} + K_2D_t \quad [2]$$

The slope of the curve of D against D_t is obtained by differentiating Eq. 2, as follows

$$\frac{dD}{dD_t} = -1.5\frac{K_3}{D_t^{2.5}} + K_2 \quad [3]$$

It is also possible to find the value of D_t corresponding to minimum raceway size. If the slope is equated to zero

$$D_t)_{min} = \sqrt[2.5]{\frac{1.5K_3}{K_2}}. \quad [4]$$

Writing out Eqs. 3 and 4 in full, that is, substituting for K_3, gives slope

$$\frac{dD}{dD_t} = \frac{8.49K_1}{D_t^{2.5}g\sqrt{S}}\left(\frac{\rho}{\rho_c-\rho}\right)\frac{W^2}{A_m^{0.25}n^{1.25}\pi^{1.25}} + K_2$$

and the tuyere diameter for minimum raceway size

$$D_t)_{min} = \sqrt[2.5]{\frac{8.49}{K_2}\left(\frac{K_1}{g\sqrt{S}}\right)\left(\frac{\rho}{\rho_c-\rho}\right)\left(\frac{K_2}{A_m^{0.25}n^{1.25}\pi^{1.25}}\right)}.$$

Acknowledgments

The authors wish to acknowledge with gratitude the work of others who made this report possible. In particular, J. H. Worley, Jr., played a major part in the development of the raceway factor. Under the guidance of R. W. Whitmore, J. A. Hereford did most of the calculation of the operational data.

References

1. J. F. Elliott, R. A. Buchanan, and J. B. Wagstaff: Physical Conditions in the Combustion and Smelting Zone of a Blast Furnace. *AIME Trans.*, 1952, vol. 194, pp. 709-717; JOURNAL OF METALS, July 1952.
2. R. A. Sweetser: *Blast Furnace Practice*. McGraw-Hill Book Co. New York, 1938.
3. J. B. Wagstaff: Further Studies of the Tuyere Zone of the Blast Furnace. *AIME Trans.*, 1953, vol. 197, pp. 895-902; JOURNAL OF METALS, July 1953.
4. G. C. Gardner: Discussion of paper by J. B. Wagstaff. *AIME Trans.*, 1954, vol. 200, p. 1307; JOURNAL OF METALS, November 1954.

Discussion of this paper sent (2 copies) to AIME by May 1, 1957 will appear in AIME *Transactions* Vol. 209, 1957, and in JOURNAL OF METALS, October 1957.

Differential High-Temperature Sulfatization Of Cuyuna Manganese Ore

This paper is confined to a discussion of some of the experimental work by the Bureau of Mines metallurgical staff at the North Central Experiment Station, Minneapolis, and in particular to a progress report describing a sulfur dioxide-air roast process now under development on a small pilot-plant scale. Although individual steps of this process have been carried out successfully on a unitized basis, further investigation will be required on a variety of manganese-bearing materials from the Cuyuna range, Minnesota, to obtain the data necessary for designing a continuous process plant. Only the Cuyuna carbonate slate formation has been studied on a pilot-plant scale.

by Charles Prasky

ABOUT five years ago the Bureau of Mines began a study, at Minneapolis, of the various methods for beneficiating the low-grade manganese deposits of the Cuyuna range. Several samples of green carbonate slate from the Cuyuna range, containing about 7 pct Mn and about 28 pct Fe, were obtained for this study. The component minerals in the carbonate slate formation were so intimately associated that mineral dressing methods were not suitable for concentrating manganese to a ferrograde product. Although upgrading of manganese and iron minerals has been effected by flotation methods, it appears that manganese cannot be separated from iron except by chemical means. Because the flotation studies at Minneapolis were carried out simultaneously with the hydrometallurgical studies, only crude slate was available for process testing.

An important economic consideration in selecting any one of the several chemical methods proposed for recovering ferrograde manganese is the availability of the chemical reagent. Fortunately, large tonnages of sulfur are available on the Cuyuna range in low-grade pyrite and pyrrhotite deposits that are readily concentrated by flotation to a suitable feed for a sulfide roasting furnace as indicated by a Bureau of Mines investigation in 1950–1951.[1] The roasted residue from the sulfide concentrates is a potential source of marketable iron oxide. Therefore, if these sulfide deposits were employed in recovering manganese, utilization of two heretofore unused mineral deposits would be accomplished.

Laboratory investigations of several proposed leaching processes were made as a preliminary step in the investigation of hydrometallurgical methods for the treatment of Cuyuna carbonate slate using sulfur as a chemical reagent. From results obtained in the laboratory tests, these leaching processes did not appear entirely suitable for treating Cuyuna carbonate slate.

The method developed at the North Central Experiment Station and selected for a more intensive pilot-plant investigation has been termed the differential high-temperature sulfatizing process.

Essentially, this sulfatizing process consists of the following steps, described in the order in which the small-scale pilot-plant investigations were made. The first and perhaps most significant step in the process consists of a sulfate roast. Carbonate slate is roasted in an atmosphere of sulfur dioxide gas and air. The overall chemical reaction for converting manganese carbonate to a sulfate at a high temperature in a sulfur dioxide atmosphere follows

$$MnCO_3 + SO_2 + \tfrac{1}{2}\,O_2 = MnSO_4 + CO_2$$
$$(\Delta H_{298^\circ K} = -64{,}180 \text{ cal per g mol}).$$

The need for concentrated sulfuric acid is avoided. Fine grinding is not essential. Removal of carbon dioxide from the slate during roasting produces a more porous structure and permits easier permeation by the sulfatizing gas mixture. The temperature limits for this conversion of manganese have been established as 600° and 850°C. Iron sulfate is unstable and is not formed at these temperatures; phosphorus is not converted to a water-soluble form; and polythionates are not formed.

The second step in the process consists simply of a water leach of the sulfatized product. Manganese sulfate in the sulfatized product is dissolved in water. Iron, phosphorus, and calcium remain in the leach residue as water-insoluble products.

The third and final step consists of the recovery of ferrograde manganese oxide from manganese sulfate leach solution. Water is evaporated from the leach solution, and impure monohydrate crystals of manganese sulfate are recovered. The moist crystals are formed into pellets or extrusions and thermally decomposed to produce a ferrograde manganese

C. PRASKY, Member AIME, is with the U. S. Bureau of Mines, North Central Experiment Station, Minneapolis.

TP 4383D. Manuscript, Feb. 20, 1956.

Papers by authors on the Bureau of Mines staff are not subject to copyright.

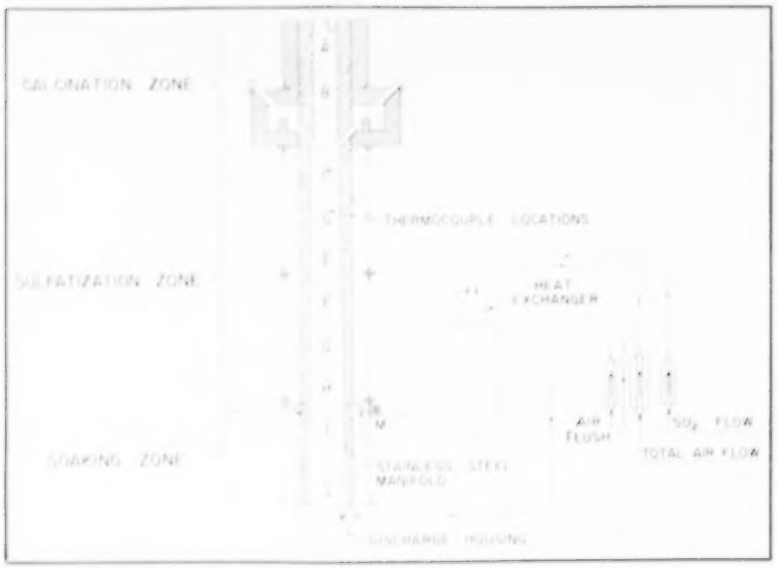


Fig. 1—Schematic drawing of 20-in.-diam shaft furnace.

product, suitable for blast-furnace feed, and sulfur dioxide, which is returned to the sulfatizing furnace.

A repetition of the three steps in the process, as follows, describes briefly how these steps were applied on a unitized basis to the pilot-plant study.

Preliminary, small-scale, batch studies of the differential sulfatization reaction step were conducted with an electrically heated stainless steel retort, suspended from a torsion balance. These batch tests were not a reproduction of larger continuous tests; they could be made in a much shorter time and were useful for determining the effect of process variables.

Commercial refrigerant sulfur dioxide in cylinders was used in the sulfatizing gas mixture to expedite the laboratory investigations. Sulfur dioxide gas, diluted with nine parts of air, approximates the composition of a gas that could be readily produced in roasting pyrite and pyrrhotite concentrates.

Although advantages of a fluidized-solids-type furnace were indicated for the sulfatizing reaction, an externally heated alloy shaft furnace was available for immediate use, with only minor adaptations. Preliminary sulfatizing tests in this 8-in. by 6-ft alloy shaft encouraged continuation of the study in a shaft furnace. Ten batch tests and two continuous runs were made with this furnace.

Products from the continuous test contained 85 to 90 pct of the manganese as the soluble sulfate.

There were no traces of phosphorus in the leach solutions of the furnace products, and manganese-iron ratios averaged about 25:1. The ratio of manganese to iron in the sulfatized material before leaching was 0.25:1.

About 48 pct of the sulfur dioxide entering the system was recovered as soluble manganese sulfate. This utilization of sulfur dioxide was considered satisfactory in view of the short column of material treated. However, the need for a larger shaft furnace designed to carry out the sulfatizing reaction on a more practical basis was indicated.

Preparations were therefore made for designing and constructing a 20-in. diam cylindrical shaft furnace in the Mines Experiment Building, on the University of Minnesota campus (Fig. 1).

The refractory-lined, 23-ft, cylindrical column of this vertical furnace contains three zones. In descending order, there is a 6-ft calcination zone at the top, a 12-ft sulfatization or reaction zone, and then a 5-ft soaking or cooling zone. Encircling the furnace at the bottom of the calcination zone is a combustion box fired with two gas burners. The combustion gases are introduced through four ports in the refractory lining of the furnace. Sulfatizing gas enters the furnace through the stainless steel manifold at the lower end of the 12-ft reaction zone and passes upward through the furnace, countercurrent to the descending carbonate slate. Sulfatized material is discharged from the bottom of the furnace by means of a modified traveling-grate mechanism.

Five continuous tests were made with this furnace. A burden of $-\frac{3}{4}$-in. pellets prepared from −65-mesh carbonate slate was employed for the first four tests, and $-\frac{3}{8}$-in. +6-mesh carbonate slate was used in the fifth test. After the material was fed into the top of the shaft furnace it was heated to a temperature of not more than 480°C. As the hot charge descended through the furnace, it was treated with sulfatizing gas in an amount not exceeding one and one-half times the stoichiometric manganese equivalent in the charge. The discharged product, which contained about 80 pct of the manganese as water-soluble manganese sulfate, was stored for subsequent use in pilot-plant leaching studies.

After operating temperatures (600° to 850°C) had been reached in the furnace, it was no longer necessary to operate the gas-fired burners to maintain temperatures. The heat of reaction of carbonate slate, treated with a countercurrent flow of sulfatizing gas, was sufficient for maintaining a self-sustaining reaction.

Several tons of an acceptable sulfatized product were stockpiled for leaching studies. In line with the unitized approach adopted in the pilot-plant development of the sulfatizing process, operation of the sulfatizing furnace was recessed temporarily while a more intensive investigation of the leaching of sulfatized products and the subsequent production of a ferrograde manganese product from the leach solution was undertaken.

Preliminary pilot-plant leaching tests on the sulfatized products were made in a rubber-lined

agitator. Manganese sulfate in the sulfatized carbonate slate was dissolved completely when leached with water at room temperature. The separation of 10 to 20 pct manganese sulfate solution from the leach residue by vacuum filtration was too slow, however, due to plugging of the filter cloth. To facilitate operations, a box filter was constructed and used as a combined leach tank and filter. A charge of −6-mesh sulfatized ore and water was agitated by forcing compressed air upward through the filter cloth and ore. The ore charge was agitated sufficiently for good leaching and stratified so that, upon reversal of air pressure, the coarse fraction of the charge was in contact with the filter cloth. The filtering rate was very rapid under these conditions. To expedite pilot-plant operations leaching equipment was improvised for a more continuous operation. Five 20-gal wooden barrels, each containing 225 lb of −⅜-in. +6-mesh sulfatized slate, were connected in series. Fresh water was added to the top of the slate in the first barrel, and the percolating leach liquor was removed by gravity from the bottom and added to the top of the next barrel in the series. Pregnant leach liquor was recovered from the fifth barrel in the countercurrent system. The sulfatized slate, containing about 6 pct soluble manganese, was leached at an average rate of 28 lb per hr; 0.66 lb of fresh water was required for each pound of slate. Leach liquor contained 102 gm Mn per l, and the coarse leach residue retained about 0.06 pct of soluble manganese. A feed material consisting of −¾-in. sulfatized pellets was leached with equal efficiency in this simulated countercurrent-percolation system.

The recovery of manganese sulfate monohydrate crystals from solution and the evaporation of water were accomplished in a gas-fired, submerged combustion unit, which was constructed in the shop. The evaporator consisted of a 9-gal, insulated, stainless steel, cylindrical tank with a conical bottom, where the manganese sulfate leach liquor was heated by the submerged burner to an average temperature of about 90°C. Two openings at the top of the tank provided an entry for the burner and an exit for the exhaust gases. Thermocouples were installed to record exhaust gas, leach solution, and discharge-slurry temperatures. A floating valve with a mercury switch was used to control the liquid level in the tank. During operation a hot slurry of $MnSO_4 \cdot H_2O$ crystals and concentrated leach liquor were removed from an opening in the conical bottom of the tank and directed onto a vacuum filter mounted directly below the tank assembly. $MnSO_4 \cdot H_2O$ crystals remained on a canvas filter and the filtrate liquor was returned to the evaporator.

During operation, the gas-fired stainless steel burner was completely submerged in the liquor. The burner consisted essentially of a 2½-in. diam, 8-in. long cylinder, which served as a combustion chamber. Combustion gases were exhausted through six holes in the bottom of the combustion chamber and bubbled through the liquor. A stainless-steel velocity tube connected the top of the combustion chamber with a flowmixer to which air and natural gas were fed.

The $MnSO_4 \cdot H_2O$ crystals obtained by vacuum filtration of the hot slurry from the evaporator contained about 15 pct of moisture and were plastic enough to be formed into pellets or fed directly to an extrusion press. Both sulfate pellets and extrusions have been prepared. The pellets, or extrusions, or the filter cake when air-dried, formed a hard, dense, cementlike product that may be fed to a shaft furnace.

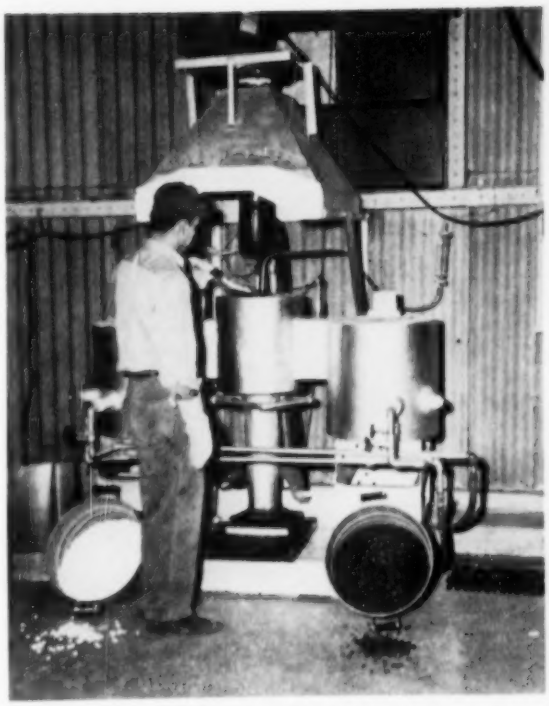


Fig. 2—6-in.-diam shaft furnace used in calcining sulfate pellets.

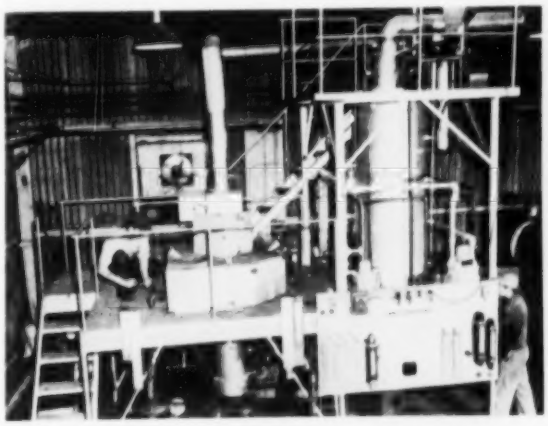


Fig. 3—LEFT: Improved shaft furnace for calcining manganese sulfate pellets. RIGHT: Shaft furnace for sulfatizing manganese with sulfur dioxide gas from calcination furnace.

In the decomposition studies of sulfate pellets, made in a small shaft furnace (Fig. 2), the sulfate pellets did not melt or stick together. Over 95 pct of the sulfur was removed, and the SO_2 content of the exhaust gases was 7 pct. A second pass through the furnace reduced the sulfur content of the pellets to about 0.2 pct, and the fired pellets contained over 50 pct Mn with a Mn:Fe ratio of about 25:1.

An improved shaft furnace designed for the decomposition of sulfate pellets is now under construction (Fig. 3). Future furnace studies will include the effect of adding carbon to increase the rate

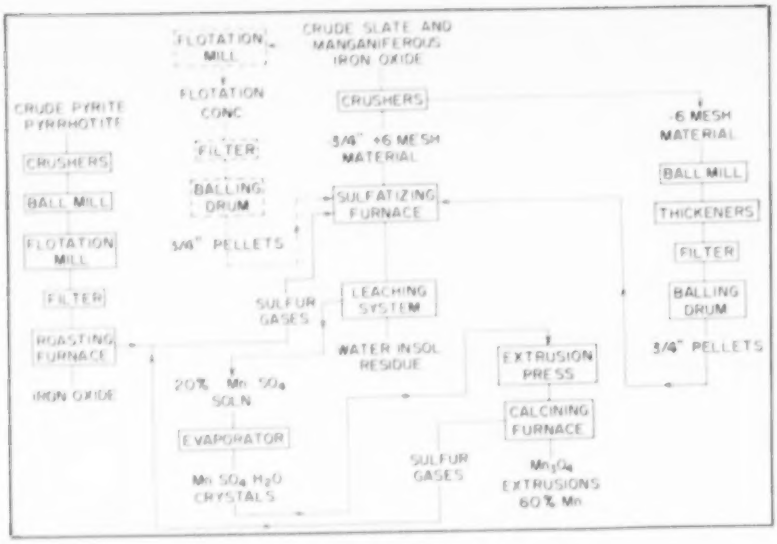


Fig. 4—Tentative flowsheet of high-temperature differential sulfatizing process.

of decomposition and to raise the SO_2 content of the exhaust gases. A small sulfatizing shaft furnace is being installed and will be used to determine the feasibility of sulfatizing raw ore with sulfur dioxide gas from the decomposition of sulfate pellets. Both units will be in operation soon.

Although a good deal of process development work on the sulfatizing process remains to be carried out, particularly in regard to the sulfate decomposition step, the preliminary operating results have been encouraging. An evaluation of these results disclosed the following:

1) A shaft furnace was suitable for converting Cuyuna manganese to a water-soluble sulfate. The amount of iron converted to sulfate was insignificant. The 12-ft reaction column of the 20-in. diam shaft was considered adequate for efficient utilization of sulfur. When operating conditions appeared optimum, no trace of sulfur dioxide or sulfur trioxide could be detected in the furnace exhaust gases. Fine grinding of Cuyuna carbonate slate was not essential for the sulfatizing treatment; however, a feed for the sulfatizing roast consisting of fine, ground flotation concentrate may possibly be treated more efficiently in a fluidized-solids-type reactor. Future studies of the sulfatizing step should include the use of such a reactor.

2) Fine grinding was not essential for extracting soluble manganese from the sulfatized material in a countercurrent-percolation system. Both coarse slate and pellets were leached efficiently in the pilot-plant simulated countercurrent-percolation system. Acid-resistant equipment will be required to handle the manganese sulfate solution, which has a pH of about 2.

3) Evaporation of water and precipitation of the monohydrate crystals of manganese sulfate in a submerged-burner-type evaporator was satisfactory; thermal efficiency of the small pilot-plant unit was 78 pct. Any conventional vacuum filter or centrifuge should be adequate for separating the crystals, providing it is resistant to solutions having a pH of 1.0.

4) Moist filter cake of manganese sulfate monohydrate may be fed to an extrusion press and a uniform product obtained suitable for feed to a shaft furnace. It is expected that the addition of lignite to the sulfate extrusions will increase the rate of thermal decomposition and raise the sulfur dioxide content of the exhaust gases.

5) Manganese oxide products obtained from the treatment of raw carbonate slate in the pilot plant contained 50 to 60 pct Mn. A product containing 60 to 65 pct Mn probably can be obtained in a continuous process plant. In addition to the carbonate slates, the Cuyuna brown and black formations will be treated, as well as a blend of the three general types. Magnesium, the largest contaminant in the manganese oxide product from carbonate slates, is present in smaller quantities in the marginal black and brown deposits. The slate materials contain as much as 3.50 pct MgO, whereas the marginal black and brown deposits contain about 0.6 pct MgO. Beneficiation of these materials before chemical processing might permit recovery of higher grade manganese oxide products low in MgO.

The tentative flowsheet (Fig. 4) shows briefly how the sulfatization process can be adapted to the treatment of crude carbonate slate and marginal manganese oxide material.

Iron oxide resulting from the roasting of pyrite and pyrrhotite concentrates for the production of sulfatizing gas, and iron oxide recovered from leach residue following extraction of soluble manganese, might be beneficiated to produce a marketable material.

Pilot-mill studies of the sulfatizing process are being continued to determine more fully the practicability of the procedures that are being developed and the amenability of a variety of manganiferous carbonate slates and oxidized materials from the Cuyuna range to these procedures. Future studies should include the process testing of manganese concentrates obtained from the low-grade materials by flotation methods to obtain more complete operating data for commercial application and cost estimation.

References

1 J. W. Pennington and V. C. Davis: *Investigation of Iron Sulfide Deposits in South Central Aitkin County and Carlton County, Minn.* RI 4953, 1953.

2 *Chemical Engineers' Handbook*, John H. Perry, ed., McGraw-Hill Pub. Co., New York, 1950.

Discussion of this paper sent (2 copies) to AIME by May 1, 1957 will appear in AIME *Transactions* Vol. 209, 1957; JOURNAL OF METALS, October 1957; and in MINING ENGINEERING, 1957.

AIME OFFICERS:

PRESIDENT—GROVER J. HOLT

PAST-PRESIDENT—C. E. REISTLE, JR.

PRESIDENT-ELECT—A. B. KINZEL

VICE-PRESIDENTS—E. C. BARTON, W. A. DEAN, L. E. ELKINS, J. L. GILLSON, W. W. MEIN, JR., ROGER V. PIERCE

TREASURER—C. H. DODSON

SECRETARY—ERNEST KIRKENDALL

AIME STAFF:

ASS'T. SECRETARIES—J. B. ALFORD, H. N. APPLETON, E. J. KENNEDY, JR.

ASS'T. TREASURER—P. J. APOL

FIELD SECRETARY & ASS'T. SECY.—N. E. O'BRIEN, 707 NEWHOUSE BLDG., SALT LAKE CITY 1, UTAH

AIME NEWS

Blast Furnace-Open Hearth Conference Scheduled For April 8-10, in Pittsburgh

The 40th Blast Furnace, Coke Oven and Raw Materials, and National Open Hearth Conferences scheduled for April 8-10, at the Penn-Sheraton Hotel, Pittsburgh, will feature a plant trip to the Weirton Steel Co.'s plant in West Virginia. A special train direct to Weirton has been reserved, leaving Pittsburgh at 9 am and returning at 5:25 pm. Luncheon will be served by the company. Cost for the trip is $3.00, and since private cars will not be permitted at the plant, participants should plan to take the train.

Registration fee for either Conference is $10.00 which includes a copy of the respective Proceedings when printed. AIME members are entitled to a $3.00 reduction upon presentation of their membership card.

In addition to the technical sessions, there will be luncheons, the Annual Fellowship Dinner and special breakfasts on Monday and Tuesday at 8 am for authors and session chairmen to plan final details regarding scheduling of papers. Officers and members of the Executive Boards will also be present. Preliminary Program appears on page 382.

First Pacific Southwest Mineral Conference

The first Pacific Southwest Mineral Industry Conference, sponsored by the AIME Nevada Section, and co-sponsored by the Southern California and San Francisco Sections, will be held in Reno, Nev., April 5-6, 1957.

Four technical sessions are scheduled for the first day at which time papers on geology, mining, metallurgy and industrial minerals will be presented, five or more papers at each session. Included are papers on *Mineral Belts in Nevada*, by R. Roberts, USGS; *Phosphate Sands in the Economy of the Pacific Rim*, by W. Smiley; *Raw Materials in the West;* and *Hole Methods of Mining and Development*.

Two field trips are planned for April 6. A visit to the diatomite mine and mill of the Eagle-Picher Co. at Clark Station, Nev., and the open pit gypsum mine and board plant of the U. S. Gypsum Co. at Empire, Nevada will be made through the Truckee River Canyon and Pyramid Lake, a remnant of prehistoric Lake Lahontan. Stops will be made at points of interest along the way. The second trip will be to Anaconda Co.'s open pit copper mine and plant at Weed Heights, Nev. Anaconda produces its own sulfuric acid from sulfur ore mined at the Leviathan mine in Alpine County, Calif. The return trip will be made by way of Virginia City and the Comstock Lode. Tours are also planned to the Mackay School of Mines at the University of Nevada in Reno.

Social events will include a luncheon, April 5, in the Fable Room, Mapes Hotel, and a cocktail party and dinner April 5, in the Redwood Room, Riverside Hotel. George A. Kiersch, geologist for the Southern Pacific Railroad and former director of the Mineral Resources Survey, Navajo-Hopi Indian Reservation, will address the luncheon on the subject of *Geological Investigations-Applications in Developing the Mineral Resources of a Region*.

Although the ladies are invited to participate in all events, a special smorgasbord luncheon will be held for them on April 5, at the Mapes Hotel. They will also visit Virginia City and Carson City on April 6.

Those attending will be left on their own, the night of April 6, and are certain to find Reno well-equipped with amusement places.

Advance registration material, reservations and programs may be obtained by writing to: William P. Johnston, Registration Chairman, 3200 West Plumb Lane, Reno, Nev.

Portland to be Site Of April Regional Meeting

Plans for the AIME 1957 Pacific Northwest Regional Conference are nearing completion, according to Don W. Johnson, general chairman. Scheduled for April 11-13, at the Multnomah Hotel, Portland, Ore., the meeting will feature an imposing roster of speakers including Dr. A. B. Kinzel, president, Union Carbide & Carbon Research Laboratories Inc. Dr. Kinzel will address the Friday night banquet on the subject of *Research in the New Metallurgy*.

Also slated to speak are: General Leslie B. Simon, vice president, Carborundum Co.; R. R. McNaughton, Consolidated Mining & Smelting Co., Trail, B. C.; Elmer C. Tveter, Dow Chemical Co.; D. W. McGlasham, Montana School of Mines; Ben H. McLeod, Dorr-Oliver Co.; George Beard, Pacific Power & Light Co.; H. F. Yancey, USBM; and L. R. Ramp, Oregon State Department of Geology.

A field trip is planned to nearby Albany, Ore., to visit the Oregon Metallurgical Corp., the Wah Chang Corp. and the Bureau of Mines. On Thursday afternoon members will have an opportunity to visit the Portland Owens-Illinois Glass plant, a multi-million dollar project, recently completed.

Special events have been arranged to keep the distaff busy and happy. On Thursday they will make a scenic tour of the Portland area. Also planned is a get-acquainted coffee hour, followed by a luncheon and fashion show.

The grand finale on Friday evening will include cocktails, a banquet and a dancing party in the Multnomah Hotel Grand Ballroom.

Registration for the meeting begins at noon on Wed., April 10, and will cost $4.00 for members, $6.00 for nonmembers, and $1.00 for the ladies.

Inquiries and mail registration should be directed to: Edward A. Vistica, 304 Public Service Building, Portland, Ore.

Preliminary Programs

Joint Events on Tuesday, April 9

6:30 pm

Reception

7:00 pm

Annual Fellowship Dinner

Blast Furnace, Coke Oven, and Raw Materials Conference

MONDAY, APRIL 8

9:30 am

Blast Furnace Practice Session

Welcoming remarks; bosh construction and bosh tuyeres; experience with stack cooling plates; blast furnace top construction; tuyere development at Bethlehem; orifice plate gas washer.

2:00 pm

Blast Furnace Theory Session

H iron process; behavior of chromium in slag-metal systems under reducing conditions; pig iron smelting in the electric furnace with prereduction.

2:00 pm

Coal and Coke Session

Symposium on maintaining and operating a coke plant during curtailment of operations.

TUESDAY, APRIL 9

9:30 am

Ore Agglomeration Session

Taconite pellets—problems of car loading, stockpiling and loading vessels at Erie Mining Co.; up-draft sintering; how theory can help make more sinter; sinter mix distribution by swinging spout method.

9:30 am

Byproduct Session

Byproduct coke industrial waste guide; biological treatment of byproduct coke plant phenolic wastes; marketing of coke byproducts.

12:30 pm

Luncheon Meeting

Everyone attending the Blast Furance, Coke Oven, and Raw Materials Conference is invited to attend this luncheon and annual business meeting.

2:00 pm

Blast Furnace and Coke Oven Joint Session

Ironmaking in the USSR—impressions gained from visits and the literature; better utilization of coking coals; high temperature testing of blast furnace coke; safety at the blast furnace.

National Open Hearth Steel Conference

MONDAY, APRIL 8

10:00 am

General Session

Welcoming remarks; announcements; McKune Award paper.

10:30 am

Basic Operations Session

Methods used during forced interruptions in open hearth operations, a symposium on results of industry-wide questionnaire; results obtained from high firing rates; open hearth design and operation in Australia, 1957.

10:30 am

Acid Operations Session

Effects of improved combustion conditions in a small cold metal shop; European methods of acid steelmaking.

12:30 pm

Physical Chemistry of Steelmaking Committee Luncheon

2:00 pm

Operating Metallurgy Session

Continuous casting of three types of low-carbon steel; an analysis of flow rates through nozzles; high speed movies showing flow characteristics of liquid steel through nozzles.

2:00 pm

Refractories and Masonry Session (I)

New approach to open hearth maintenance; prefabricating new fronts for open hearth furnaces saves time and money; open hearth roof patching; pouring refractories; an evaluation of cast refractory hot-top linings.

TUESDAY, APRIL 9

9:30 am

Refractories and Masonry Session (II)

Progress report on all-basic furnace at South Works, U. S. Steel Corp.; progress report on basic construction at Keystone Steel and Wire Co.; progress report on flat basic roof at Jones & Laughlin Steel Corp., Laclede Steel Co., and Inland Steel Co.; progress report on sprung basic roof at Republic Steel Corp.

9:30 am

Cold Metal and Basic Foundry Session

Minimum iron charge; alloy steel production in a cold metal shop; use and economics of basic lined runners; mechanical aids to labor—furnace rebuilds and operation; advantages of an all-basic furnace in a cold metal shop.

2:00 pm

Operating and Combustion Session

New trends on firing rates in the open hearth furnace; jet atomization; contribution of bath temperature control to improved open hearth production rates; influence of open hearth combustion practice on rates of heat transfer as determined by use of the hot model technique; an automatic system of fuel control.

2:00 pm

Physical Chemistry of Steelmaking Session

Significance of G. H. Herty, Jr.'s work to modern steel practice; current concepts of open hearth slag control; producing steel to make physical test requirements.

WEDNESDAY, APRIL 10

9:00 am to 5:25 pm

Plant Trip

Open to registrants of Blast Furnace, Coke Oven, and Raw Materials and National Open Hearth Steel Conferences

EJC General Assembly

A partial view is shown of the head table at the Unity Dinner, on Jan. 17, during the Engineers Joint Council annual meeting in the Statler Hotel. Left to right, J. W. Barker, EJC President; T. B. Counselman, AIME Vice President; Paul Weir, President, American Water Works Assn.; and W. L. Everitt, President, American Society for Engineering Education.

AIME Plays Major Role In Nuclear Congress

The AIME is participating in the Second Nuclear Engineering and Science Conference being held at the Convention Hall in Philadelphia, March 11-15, 1957. Three technical sessions on the metallurgy of nuclear materials have been organized under AIME sponsorship.

At the session on *Uranium Metallurgy and Radiation Effects*, Wednesday afternoon, March 13, the following papers will be presented: *The Effect of Cooling Rate on the Nucleation and Growth of Beta Uranium Hydride in Metallic Uranium* by H. R. Gardner and J. W. Riches; *Effects of Alloying Element Additions of Al, Si, Mo, Ti, V, Zr, and Nb on the Thermal Cycling Stability of Uranium* by S. T. Zegler and H. H. Chiswik; *A Study of the Tensile Transition in Alpha Uranium* by Lyle L. Marsh, Jr.; *Metallographic Studies of Neutron-Irradiated Non-Fissionable Metals* by C. A. Bruch, W. E. McHugh, and Louise J. Doig; *Effects of Grain Size on the Growth of Alpha-Uranium Under Irradiation* by R. Resnick and L. Seigle; *The Effect of Irradiation on the Tensile Properties of Uranium* by R. E. Hueschen, R. S. Kemper, and W. S. Kelly. Benjamin Lustman and C. A. Bruch will serve as chairmen of this session.

Metallurgy of Reactor Materials will be held on Thursday morning, March 14, with the following papers being presented: *Transformation Kinetics and Mechanical Properties of 0.5 and 1.0 w/o Mb-U Alloys* by E. G. Zukas; *Metastable Gamma Phase in Uranium-Base Molybdenum Alloys* by W. A. Bostrom and E. K. Halteman; *Corrosion of U-Mb Alloys in High-Temperature Water* by M. W. Burkart, I. Cohen, and R. K. McGeary; *Self-Diffusion in Thorium* by C. J. Meechan; *Internal Friction and Shear Modulus of Thorium at High Temperatures* by C. E. Dixon and H. Hori; *Effect of Cold Work on the Mechanical Properties of Zircaloy-2* by F. Forscher. Chairmen of this session will be A. R. Kaufmann and Bruce Dunnington.

A session on *Metallurgy of U-Zr and U-Nb Alloys* is scheduled for Thursday afternoon, March 14, at which time the following papers will be offered: *Effects of Oxygen on Zr-U Epsilon-Phase Alloys* by A. A. Bauer and F. A. Rough; *The Corrosion Properties of Zirconium-Base Uranium Alloys* by S. Kass; *Uranium-Columbium Alloy Diagram* by B. A. Rogers, D. F. Atkins, E. J. Manthos, and M. E. Kirkpatrick; *Continuous Cooling Transformation Studies for the U-10 wt pct Nb Alloy* by J. S. Parry, R. J. Van Thyne, and D. J. McPherson; *Effects of Irradiation on Powder Metallurgy Compacts of Uranium-Base Alloys* by J. H. Kittel, and S. H. Paine; *Radiation Stability Studies of Binary Uranium Alloys* by G. D. Calkins, J. E. Gates, A. A. Bauer, and F. A. Rough. Chairmen of this session will be H. A. Wilhelm and H. H. Chiswik.

The following miscellaneous papers are to be combined with other sessions: *Recent Uranium Redistribution in the Cameron, Ariz., Deposits* by Ralph Austin; *Uranium West of the Colorado Plateau* by D. L. David and B. J. Sharp; *Absorber Materials for Reactor Control* by W. K. Anderson and D. N. Dunning; *Patterns of Disequilibrium in Radioactive Ores* by J. N. Rosholt. These sessions were organized by F. A. Rough.

AIME is one of a number of scientific societies participating in the 1957 Nuclear Congress through the Engineers Joint Council. At this meeting more than forty major topics will be considered.

Southwest NOHC Meeting in St. Louis

An all-day meeting of the AIME Southwestern Section, NOHC was held on Feb. 8, 1957 at the Hotel Lennox in St. Louis.

Technical sessions held in the morning and afternoon featured two S. W. Section Award papers: *Charging Rate and Furnace Performance* by L. B. Lindemuth, Jr.; and *Some Factors Affecting Sulfur Control in Open Hearth* by R. E. Ragain. Other papers presented were: *Practices Employed in the Use and Maintenance of Immersion Thermocouples* by S. Purcell and G. W. Brooks; *Operating Problems Involving Intermittent Operations in a Cold Metal Shop Using Basic Construction* by A. H. Sommer; *More Recent Developments in Use of Oxygen* by G. Miller and C. F. Henzelman; *Open Hearth Bottom Repairing: Materials Used and Procedures* by D. Taylor, M. Tarris, and C. Campbell; *Metallurgical Problems Connected with Open Hearth Operations* by S. Purcell and M. J. Tonebaum; and *Statistics on Open Hearth Brick Usage—S. W. Section* by A. H. Sommer.

On the lighter side, the get-together also included luncheon, a suppliers cocktail party and a Fellowship Dinner which was followed by entertainment.

Regional Reactive Metals Conference in Los Angeles

The Second Reactive Metals Conference will be held under the auspices of the AIME Southern California Section at the Ambassador Hotel in Los Angeles, May 28-29.

The conference will be concerned with the resources, production, fabrication, properties, and use of such metals as beryllium, boron, columbium, molybdenum, tungsten, uranium and vanadium, among others.

A number of companies will exhibit equipment, important in the mining and processing of reactive metals, and show examples of fabrication techniques.

The Metals and Mining Branches will hold concurrent meetings on the first day, and joint meetings on the second. The tentative program includes sessions on the metallurgy of titanium, zirconium, and hafnium on Tuesday morning, May 28. That afternoon there will be a session on fabrication techniques including vacuum melting extrusion, and forging, welding, and powder metallurgy.

Featured speaker at the Tuesday dinner will be James Boyd, former USBM director, and now vice president of Kennecott Copper Corp. His topic is *The Effect of Location of Reactive Metal Resources on the Industrial Development of the U. S.*

The Joint Mining and Metals Session on the morning of May 29, will include papers on beneficiation, refining and future trends in titanium electrometallurgy. Featured speaker for the Wednesday luncheon is Bruce S. Old, president, Nuclear Metals, who will discuss *Current Interests in Reactive Metals.*

Registration fee is $3.00 for AIME members, and $5.00 for others. For further information write B. S. Mesick, General Chairman, A. D. Little Inc., 727 W. 7th St., Los Angeles 17.

Program—Regional High-Temperature Materials Conference

TUESDAY, APRIL 16

Welcoming Remarks by G. M. Ault, *General Chairman* and R. F. Hehemann, *Section Chairman*

Strengthening by Mechanical Dispersions

Observations of SAP and Present Theories for Its Remarkable High Temperature Strength: *Fritz Lenel*, Rensselaer Polytechnic Institute

Research in Progress on Oxide-Metal Systems: *Oliver Preston and N. J. Grant*, Massachusetts Institute of Technology

The Development of SAP Type Structures in Titanium for Elevated Temperature Service: *R. W. Jech, E. P. Weber, and A. D. Schwope*, Clevite Research Center

Dispersion Hardened Alloy Molybdenum: *John Wulff*, Massachusetts Institute of Technology

Cobalt and Nickel Base Alloys

Status and Future of Nickel Base Alloys: *F. L. Ver Snyder*, General Electric Co.

An Investigation of High Temperature Properties of Nickel Base Alloys Using Balanced Experimental Design: *T. L. Robertshaw*, Universal-Cyclops Steel Corp.

Evaluation of a Cast Nickel Base Alloy for Use as a Turbojet Engine Bucket Material at 1650°F: *R. A. Signorelli, J. R. Johnston, and J. W. Weeton*, Lewis Flight Propulsion Laboratory, National Advisory Committee for Aeronautics

W-545—A New Higher Temperature Turbine Disc Alloy: *J. T. Brown and J. Bulina*, Westinghouse Electric Corp.

Status and Future of Cobalt-Base Alloys: *Glenn Fritzlen*, Haynes Stellite Co.

ML-1700 Cast Turbine Bucket Alloy: *R. J. Morris*, Aircraft Gas Turbine Div., General Electric Co.

Temperature Dependence of the Hardness of Secondary Phases in Turbine Bucket Alloys: *J. H. Westbrook*, General Electric Co.

Gas-Metal Systems and Oxidation

The Niobium-Hydrogen System: *T. D. McKinley*, E. I. du Pont de Nemours and Co., Inc.

Studies of Niobium-Oxygen and Niobium-Titanium-Oxygen Systems: *K. M. Carlsen and W. I. Pollock*, E. I. du Pont de Nemours and Co., Inc.

Oxidation Resistance of Binary Chromium-Base Alloys: *E. P. Abrahamson, II, and N. J. Grant*, Massachusetts Institute of Technology.

The Oxidation of Tungsten and Molybdenum from 1800°-2500°F: *J. W. Semmel, Jr.*, General Electric Co.

High Temperature Oxidation of Gas Turbine Alloys: *J. F. Radavich*, Purdue University

Conference Dinner

Fellowship Hour

6:15 pm Terrace of the Rainbow Room

Dinner

7:00 pm Rainbow Room

WEDNESDAY, APRIL 17

Cermets and Intermetallics

Cermets and Bonded Hard Metals: *J. T. Norton*, Massachusetts Institute of Technology

Recent Developments in Sintered Titanium Carbide Compositions: *J. Wambold*, Kennametal Inc.

Recent Advances in Infiltrated Titanium Carbides: *H. Hawendel and C. G. Goetzel*, Sintercast Corp. of America

Wettability and Microstructure Studies in Liquid Phase Sintering: *M. Humenik, Jr. and N. M. Parikh*, Ford Motor Co.

Modes of Fracture and Slip in Cemented Carbides: *N. M. Parikh*, Ford Motor Co.

Materials Based on Intermetallic Compounds: *Robert Steinitz*, American Electrometal Div., Firth Sterling Inc.

The Use of Cermets for Gas Turbine Blades: *C. G. Deutsch*, National Advisory Committee for Aeronautics

Effect of Testing Environment on High Temperature Properties

Effect of Testing Environment on Properties of Alloys at High Temperatures: *Donald Douglas*, Oak Ridge National Laboratory

Some Observations on the Effect of Atmosphere on Creep Rupture: *P. Shahinian and M. R. Achter*, U. S. Naval Research Laboratory

Stress-Rupture Properties of Nickel Tubes at 1500°F and Varying Environments: *H. T. McHenry and H. B. Probst*, National Advisory Committee for Aeronautics

The Effect of Testing Atmospheres on the Creep Rupture Properties of Molybdenum Base Alloys at 1800°F: *Dean D. Lawthers and M. J. Manjoine*, Westinghouse Electric Corp.

Refractory Metals

Chromium and Its Alloys: *R. W. Fountain and M. Korchynsky*, Electro Metallurgical Co., Div. of Union Carbide & Carbon Corp.

Transition Temperatures of Chromium and Chromium Base Alloys: *E. P. Abrahamson, II, and N. J. Grant*, Massachusetts Institute of Technology

Molybdenum, Its Alloys and Its Protection: *Julius Harwood*, Office of Naval Research

Properties of Molybdenum Turbine Buckets: *R. G. Frank*, Aircraft Gas Turbine Div., General Electric Co.

Processing and Properties of Selected Experimental Molybdenum-Base Alloys: *T. K. Bedden*, Aircraft Gas Turbine Div., General Electric Co.

Tungsten, Tantalum, Columbium, and Rhenium: *John Pugh*, General Electric Co.

Effect of Vacuum Melting on Properties

Effects of Vacuum Melting Gas Content and Metal Structure: *C. M. Hammond and R. A. Flinn*, University of Michigan

Quality Control Achieved by Vacuum Melting and Effects on High Temperature Properties: *F. N. Darmara*, Utica Drop Forge and Tool Corp.

Evaluation of Vacuum Melted Vacuum Investment Cast Nickel Base Alloys: *P. W. Beamer and J. J. Eisenhauer*, Austenal Laboratories Inc.

Consumable Electrode Vacuum Melting of High Temperature Alloys: *R. K. Pitler, E. E. Reynolds, and W. W. Dyrkacz*, Allegheny-Ludlum Steel Corp.

Influence of Type of Crucible on Creep Rupture Properties at 1600°F of a Vacuum Melted 55-Ni, 20-Cr, 15-Co, 4-Mo, 3-Ti, 3-Al Alloy: *R. F. Decker, J. P. Rowe, and J. W. Freeman*, University of Michigan

The Effect of Vacuum Melting on the High Temperature Properties of Nickel Base Super Alloys: *F. M. Richmond*, Universal-Cyclops Steel Corp.

Papers Requested For High Temperature Meet

The AIME, IMD High Temperature Materials Committee is sponsoring a symposium at the Second World Metallurgical Congress in Chicago, November 1957. The topic of the symposium is *The Relation of Structure to High Temperature Properties*. The Committee can use manuscripts dealing with the stability of microstructure at high temperatures, structural changes during high temperature service, and the effect of different structures on high temperature properties. Papers submitted to this symposium may also be sent to the AIME for publication in the usual manner. A 100-200 word abstract of papers for presentation should be sent by May 15, 1957, to R. W. Guard, Alloy Studies, General Electric Research Laboratory, Schenectady, N. Y.

High-Temperature Materials Conference Set April in Cleveland

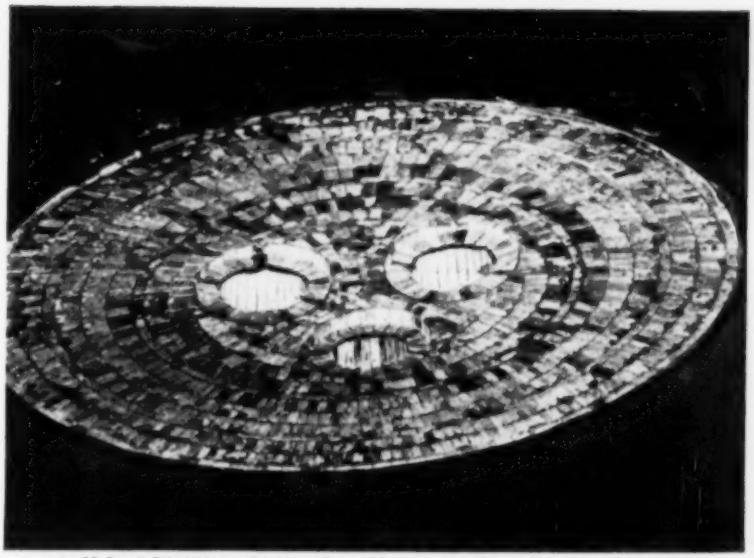
High-Temperature Materials is the subject of a two-day conference to be held at Hotel Carter, Cleveland, April 16-17, 1957, under the sponsorship of the AIME Cleveland Section. The High-Temperature Materials Committee of the AIME-IMD has cooperated in planning the technical program (see page 384.)

This conference will cover the classes of materials that are attractive for use at 1500°F in aircraft, missiles, and nuclear reactors. For each class, the present status of development, basis of strength, problems and shortcomings, and future will be discussed. Additional topics include the effects of vacuum melting and testing environment on high-temperature properties.

Each major topic will be summarized by a competent authority, followed by contributions of recent research or results of research in progress. Among the major topics to be discussed are: cobalt-base and nickel-base alloys; refractory metals; cermets and intermetallics.

This conference will be of significant interest to engineers and scientists working in the aircraft, missile, and nuclear fields. The need for higher operating temperatures make the design and development of new materials imperative.

A fellowship hour followed by dinner will be held on Tuesday evening, April 16, at which time Willy Ley will speak on *Conquest of Nearby Space*.



An 18-ft. all-SHAMVA roof laid up for a 50-ton electric furnace melting alloy steels.

In electric furnace operations

SHAMVA MULLITE GIVES YOU OUTSTANDING SERVICE

"Shamva" Electric Furnace Roof Brick is a coarse and open type refractory, giving you the extreme spalling resistance necessary in top charge electric furnace roofs.

- *High fusion point (3335°F.)*
- *High softening point (over 3000°F.)*
- *Low coefficient of expansion (3.66 x 10^{-6} per °C.)*
- *Anti-spalling (0.7% at 3000°F. Preheat, A.S.T.M. test)*
- *High load bearing strength (—3.1%, at 3000°F., 1½ hrs., 25 p.s.i. A.S.T.M. test)*
- *Low heat conductivity for greater furnace efficiency*

With "Shamva" Mullite Brick, roof life and production increase, down time and labor costs decrease.

Let our field engineers assist in your refractory installation.

WRITE TO: *Mullite Works, Laclede-Christy Division, H. K. Porter Company, Inc., Shelton, Conn.*

Distributors in principal cities

HKP MULLITE WORKS LACLEDE-CHRISTY DIVISION H. K. PORTER COMPANY, INC.

PERSONALS

J. R. GORDON

J. Roy Gordon has been elected executive vice president, The International Nickel Co. of Canada Ltd. and INCO, the company's U. S. subsidiary. He has been a vice president of the former since 1953 and of the latter since 1955. A former president and director of the Ontario Mining Assn. and member of the CIM, Mr. Gordon was the 1948 recipient of the Institute's Medal "for his contributions to process metallurgy in the smelting and refining of nickel, and improvements in metallurgical nickel recovery."

Fred L. Stubb has recently become associated with Carpco Engineering & Mfg. Co.'s research division in Jacksonville, Fla. He had been on assignment in Coolangatta, Queensland, Australia.

Charles J. Hunter has transferred from Gary Steel Works, U. S. Steel Corp., Gary, Ind., to the company's South Works in Chicago.

Frank E. Jaumot, Jr., former chief, of the Physics of Metals Section at Franklin Institute, Philadelphia, is now at Delco Radio Div., General Motors Corp., in Kokomo, Ind., where he is assistant chief engineer in charge of semiconductor research and development.

W. Martin Fassell, Jr., former professor of metallurgical engineering at the University of Utah, Salt Lake City, is now at the Central Research Laboratory, Howe Sound Co., Salt Lake City.

H. H. Blosjo has joined the staff of the Steel Foundry, Malleable Iron Fittings Co., Branford, Conn., as process engineer. He had been chief metallurgist at Minneapolis Electric Steel Castings Co., Minneapolis.

H. H. BLOSJO

B. D. THOMAS

B. D. Thomas has been named director of Battelle Memorial Institute. A member of the Institute's executive and technical staff since 1934, Dr. Thomas was appointed assistant director in 1942. His activities have included the organization and direction of Battelle's first chemical research division in 1939, the establishment of research laboratories abroad, and development of the Institute's recently completed nuclear research center.

Howard F. Jelinek recently joined the Metallurgy Div., Argonne National Laboratory, Lemont, Ill., as an assistant metallurgical engineer. Mr. Jelinek received a B.S. degree in metallurgical engineering at the South Dakota School of Mines and Technology in June, 1956.

Murray J. Miller has retired from Republic Steel Corp., Gadsden, Ala., with which he had been associated for 33 years, to set up his own consulting service.

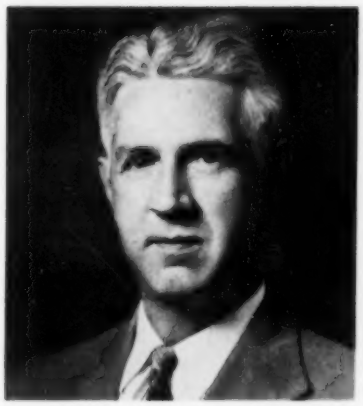
Robert C. Meyer, formerly with The Anaconda Co., Grants, N. M., is now with The American Smelting & Refining Co., El Paso Smelter Works, Texas.

Clyde Wyman, former chief metallurgist, Burnside Steel Foundry Co., Chicago, is now with Vulcan Steel Foundry Co., Oakland, Calif. In his new post Mr. Wyman will be manager of product development.

J. Ray Coulter is the new manager of manufacturing, Agricultural Chemicals Div., American Cyanamid Co., New York.

John W. Farrell has completed his studies at the University of Wisconsin, Madison, and is now a junior assistant metallurgist for the Electro Metallurgical Co., Niagara Falls, N. Y.

Donald L. Stephens is currently enrolled in the graduate school, Carnegie Institute of Technology, as a candidate for the doctorate degree.



C. A. RODGERS

Clyde A. Rodgers has been named assistant superintendent of oxygen steelmaking production, Kaiser Steel Corp., Fontana, Calif., in the first western plant to produce high quality steel by injecting pure oxygen into molten iron and scrap. A graduate of Ohio State University, Mr. Rodgers came to Kaiser Steel in 1946 from Youngstown Sheet & Tube Co., Ohio, where he had been metallurgical observer and engineer in the open hearth division for 11 years.

R. G. Bowman, formerly with The Anaconda Co., Anaconda, Mont., has joined the staff of Behre, Dolbear & Co., N. Y.

R. MADDIN

Robert Maddin, professor of metallurgy, University of Pennsylvania, has been appointed director of the School of Metallurgical Engineering. Dr. Maddin has taught at New Haven Junior College and Johns Hopkins University, and was a visiting lecturer at MIT and the University of Birmingham, England. For the past eight years he has been studying the deformation and recrystallizaion of metals for the U. S. Office of Naval Research. In 1956 he was awarded a research contract with the AEC for work on the effect of plastic stresses on diffusion.

Rare Earths

OXIDES METALS SALTS

MICHIGAN CHEMICAL CORPORATION NOW PRODUCES RARE EARTHS in large quantities to exacting purity specifications. New research and plant facilities staffed by scientific and technical groups, combined with the company's fine chemicals and pharmaceutical units, have made possible this progress in rare earth chemistry and metallurgy.

Research facilities and personnel are available to help science and industry in the development of Rare Earth oxides, salts and metals applications.

Write for information on availability of MC Rare Earth products and for technical data sheets on their characteristics.

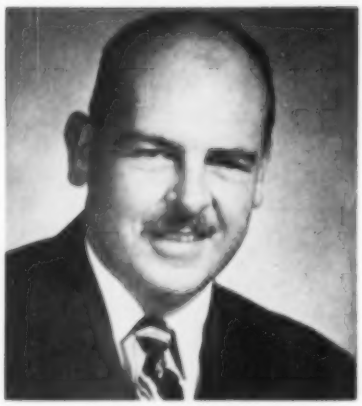
MC

RE-56-4
*Trademark

MICHIGAN CHEMICAL CORPORATION

558 North Bankson Street, Saint Louis, Michigan

LUTETIUM — YTTERBIUM — THULIUM — ERBIUM — HOLMIUM — DYSPROSIUM — TERBIUM
GADOLINIUM — EUROPIUM — SAMARIUM — YTTRIUM



R. J. McCARTHY

Robert J. McCarthy, president and general manager of Missouri Refractories Co., Los Angeles, will remain as head of the firm while acting as general manager, Atlantic Div., Mexico Refractories Co. Prior to organization of the Missouri Co. in 1951, Mr. McCarthy was engaged in firebrick and general construction work for 19 years. His professional affiliations include AIME, ASM and the American Ceramic Society.

Loren J. Westhaver was recently appointed executive vice president, Columbia-Geneva Steel Div., U. S. Steel Corp. Formerly vice president and manager of Utah operations for the Geneva Steel Co. and Columbia Iron Mining Co., he has been in charge of the division's operations since 1955. Mr. Westhaver joined U. S. Steel in 1928.

Frederick E. Weil recently joined the Atomic Energy Div., American Standard Mfg. Co., Redwood City, Calif., as associate metallurgist. He had been a research assistant and graduate student at Massachusetts Institute of Technology.

N. W. GRIFFIN

Noel W. Griffin has become works manager of Eastern Smelting Co., Ltd., Penang, Malaya. He had been metallurgical engineer with the company.

John M. Parks left the Research Laboratory, Air Reduction Co. Inc., Murray Hill, N. J., to join the Lincoln Electric Co., Cleveland.

Fred T. Inouye is associated with North American Aviation Inc., Downey, Calif., as metallurgist. He had been with the Bureau of Ships, Dept. of the Navy, Washington, D. C.

John O. Hilliard has become blast furnace consultant for Companhia Siderurgica Nacional, Brazil.

H. S. Blumberg has resigned his position as chief metallurgist at the M. W. Kellogg Co., Jersey City, to set up his own consulting office in New York.

Thomas P. Philip resigned from O'okiep Copper Co. Ltd., Nababeep, C. P., Union of South Africa. He is in Tucson, Ariz., where he will attend the University of Arizona for the next few years.

Russell G. Sherman, former research metallurgist in the technical department, Titanium Metals Corp. of America, Henderson, Nev., is now chief metallurgist, Allen Manufacturing Co., Hartford.

H. CZYZEWSKI

Harry Czyzewski, president and founder of Metallurgical Engineers Inc., Portland, Ore., is the new president of the Professional Engineers of Oregon. Mr. Czyzewski, who earned his B.S. and M.S. degrees in metallurgical engineering at the University of Illinois, belonged to many scientific and academic honorary societies, and became the winner of AIME's National Award Undergraduate Paper Contest. Prior to organizing his company, he had been research metallurgical engineer, Caterpillar Tractor Co., Peoria, Ill., and was for two years assistant professor of physical metallurgy research at the University of Illinois, Urbana.

James H. Rogers is with General Refractories Co., Latrobe, Pa.

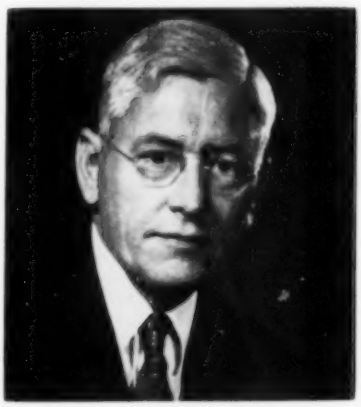
Max C. Farmer has been appointed technical director of the Beryllium Corp., Reading, Pa. Formerly general superintendent of the corporation, Mr. Farmer joined ALCOA as assistant chief, Engineering Div., in 1947. He has been serving as staff metallurgist, Materials Advisory Board, the National Academy of Sciences, Washington, D. C.

Arthur G. Metcalfe is supervisor of physical metallurgy at Armour Research Foundation, Illinois Institute of Technology, Chicago. Dr. Metcalfe, who was metallurgist at the Hard Metal Tools Co., Coventry, England, prior to joining the Foundation, will supervise research in magnetic and semiconductor materials.

R. F. GIESELMAN

Richard F. Gieselman has resigned his position as supervisor of quality control in the Ordnance Development Dept., Eureka Williams Corp., Bloomington, Ill. He is now in the Plant Apparatus Dept., Westinghouse Electric Corp., Pittsburgh.

John Chipman, past chairman, AIME Iron and Steel Div., will deliver the 31st Annual Priestley lectures at Pennsylvania State University, April 1-5. Dr. Chipman, who is head of the department of metallurgy at MIT, will discuss *Chemistry in the Metallurgy of Iron and Steel.*



J. CHIPMAN

C. M. SQUARCY

C. M. Squarcy has been promoted to manager of iron production, Indiana Harbor Works, Inland Steel Co., E. Chicago, Ind. He had been superintendent of the Blast Furnace Dept.

W. O. Philbrook has advanced from associate professor to full professor of metallurgical engineering at the Carnegie Institute of Technology in Pittsburgh.

Paul R. Kruesi has become manager of the process division, Heavy Minerals Co., Chattanooga, Tenn. He had been manager of research and development in the company.

Edward G. Counselman has been appointed Washington representative of the H. K. Porter Co. Inc., Pittsburgh. He comes to Porter from the Dravo Corp., where he had served since 1953 as sales engineer.

J. F. THOMPSON

International Nickel has announced its decision to proceed with operations for a four-year project in northern Manitoba, Canada, constituting the largest single investment of any kind in that province. The company will honor **John F. Thompson,** chairman of the board, who this year completed 50 years of service with Inco, by naming one of its two mines, as well as the new town plant site, after Dr. Thompson.

John F. Richards has recently joined the Research and Advanced Development Div., Avco Manufacturing Corp., Lawrence, Mass., as supervisor of metallography and associate scientist in metallurgy. Mr. Richards had been assistant supervisor of metallography, Atomic Energy Div., Sylvania Electric Products Co., Bayside, N. Y.

C. B. Sawyer has resigned his post as president, Brush Laboratories Co., Cleveland, to head Sawyer Research Products Inc., Eastlake, Ohio.

Edward J. Ramaley has recently become associated with the Glenn L. Martin Co. in Denver, Colo. He was formerly an engineering consultant on manufacturing problems.

George H. Enzian has transferred from the metallurgical research division, Jones & Laughlin Steel Corp., Pittsburgh, where he had been assistant manager, to Gateway Center, the company's main headquarters in Pittsburgh.

J. Monaghan has been transferred from Union Carbide & Carbon Corp., New York, to the company's offices in Geneva.

Charles Locke has left Westelectric Castings Inc., Los Angeles, to join the staff of Crucible Steel Casting Co., Cleveland.

Robert C. Brinton has been promoted to smelter superintendent, White Pine Copper Co., White Pine, Mich.

180 YEARS OF PUBLISHING

LOOKING FORWARD

Robert Fulton's marvelous steamboat
fired the minds of forward-looking men
when she churned up the Hudson
in 1807.

To the House of Wiley, founded that same year,
the *Clermont's* voyage opened up
a new and exciting frontier in publishing.

If America were to exploit her new industrial age,
pioneering books would have to be provided.
It is this demand — greater in 1957 than ever —
that Wiley has been meeting successfully
for one hundred and fifty years.

Today, the *Clermont's* atom-powered granddaughter
slips through the seas . . .
the scientific community continues to expand . . .
and, planning for the future,

John Wiley & Sons looks forward to publishing
an ever-greater number of distinguished books
in all areas of pure and applied science.

JOHN WILEY & SONS, Inc.

440 Fourth Avenue, New York 16, N. Y.

Brothers **Richard E. Westerman** and **Edwin J. Westerman** are both full-time students at Rensselaer Polytechnic Institute, Troy, N. Y., where they received industrial fellowships for a Ph.D. degree.

Jacob W. Cox has been promoted to director of raw materials, American Steel & Wire Div., U. S. Steel Corp., Cleveland. Associated with the company for 20 years, he has been assistant to the general superintendent, Donora Steel and Wire Works in Donora, Pa.

Carl R. Garr has transferred to Atomic Power Div., Bettis Plant, Westinghouse Electric Corp., Pittsburgh, where he will serve as senior engineer. He had been research assistant, Case Institute of Technology, Cleveland, for six years.

MEMBERSHIP

Proposed for Membership
Metals Branch, AIME

Total AIME membership on Dec. 31, 1956, was 26,298; in addition 3,415 Student Associates were enrolled.

ADMISSIONS COMMITTEE

R. H. Caples, Chairman; F. A. Ayer, Vice-Chairman; A. C. Brinker, R. H. Dickson, C. R. Dodson, R. B. Fulton, T. D. Jones, F. W. Hanson, Sidney Rolle, F. T. Sisco, O. B. J. Fraser, F. W. McQuiston, Jr., A. R. Lytle, L. P. Warriner

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

Members

Donald E. Cozad, Long Beach, Calif.
Joseph George Dryer, Glencoe, Ill.
Sumner Norton Levine, Greenwich, Conn.
Robert E. Maringer, Columbus, Ohio
P. Mominh, Dravosburg, Pa.
Morris W. Mote, Jr., Columbus, Ohio
John M. Ohno, Fontana, Calif.
John J. Park, Washington, D. C.
Stewart D. Rand, Ingomar, Pa.
E. V. Roberts, Scotch Plains, N. J.
Joseph Singer, Pittsfield, Mass.
Giuseppe G. Testero, Milano, Italy
Joseph R. Vilella, Monroeville, Pa.
Herbert D. Wedge, Marietta, Ohio
Joseph W. Wilson, Los Altos, Calif.

Associate Members

Theodore H. Gerken, Brooklyn
Ernesto Gerardo Hoyos, Mexico City, Mexico
John J. McGlone, Shaker Heights, Ohio
R. S. Richards, Anchorage, Alaska

Junior Members

Ellsworth Armand Field, Brooklyn
Simon C. Moss, Boston
Dorothy F. Radulski, Monroeville, Pa.

CHANGE OF STATUS

Associate to Member

J. H. Brindle, Pittsburgh
Frederick Isaac Brown, Jr., Little Rock, Ark.
Chih Wen Chen, New York
M. E. Cieslicki, Cincinnati
Joseph Garland, Providence
William R. Kerr, Ontario, Calif.
Henry P. Kirchner, Jr., Corning, N. Y.
Henry Kopczewski, Cleveland
H. P. Leighly, Jr., Denver
Lowell T. Lloyd, Chicago
Robert Lowrie, Lewiston, N. Y.
John P. Lyle, Jr., New Kensington, Pa.
Edward J. Martin, Park Ridge, Ill.
Oliver W. Moles, Plainfield, N. J.
Arthur S. Nowick, New Haven, Conn.
V. A. Phillips, Sheffield, England
George A. Ratz, Pittsburgh
Robert G. Redelfs, Monaca, Pa.
George H. Schipperelt, Columbus, Ohio
Roger R. Turk, La Mirada, Calif.

REINSTATEMENT—CHANGE OF STATUS

Student to Member

George A. Last, Bountiful, Utah

OBITUARIES

Everette Lee DeGolyer

An Appreciation by
Lewis W. MacNaughton

Everette Lee DeGolyer (Honorary Member 1914), senior chairman of the board of DeGolyer & MacNaughton, consultants to the petroleum industry, and director of many companies engaged in the petroleum and related industries, died at his office in Dallas on Dec. 14, 1956.

Mr. DeGolyer, who was affectionately known to his many friends as "De," was born on Oct. 9, 1886, of pioneer parents on a farm near Greensburg, Kan.

Mr. DeGolyer's interest in geology began even before he attended the University of Oklahoma. During his summer vacations he worked with the USGS, attracting the attention of C. W. Hayes. Shortly thereafter, Dr. Hayes, who was then building the geological staff of the Mexican Eagle Oil Co. Ltd., encouraged him to join his staff beore graduation. While in Mexico, Mr. DeGolyer staked the location for the Potrero Del Llano Well No. 4, one of the world's largest oil wells. He returned to the University and was graduated with a B.A. in geology in 1911, after which he was appointed chief geologist of Mexican Eagle Oil Co. Ltd.

From this point onward, his organizational ability was displayed in many of his activities. He helped form the Amerada Petroleum Corp. in 1919 and in 1925 its subsidiary, the Geophysical Research Corp. He also aided in the organization of Geophysical Service Inc. Another pioneering service company, Core Laboratories Inc., was formed at his instigation. After he resigned as Board Chairman of Amerada, he organized his own small company, the Atlatl Royalty Corp., where his primary interest lay in exploring for new oil fields. Although he was instrumental in organizing a number of companies engaged in various phases of the petroleum industry, he much preferred to study and analyze and explore situations rather than handle administrative details. In 1936, Lewis W. MacNaughton joined with him as consultants for the petroleum industry. This association was formalized under the name of DeGolyer & MacNaughton on Jan. 1, 1939, and Mr. DeGolyer remained the active senior member of this firm until his death.

During these years, Mr. DeGolyer also devoted much time to a wide variety of other activities. He was Distinguished Professor of Geology at the University of Texas in 1940, and was with the Petroleum Administration for War in Washington for over two years. He also served with the Interstate Oil Compact Commission, National Petroleum Council, Military Petroleum Advisory Board, and the AEC Advisory Committee on Raw Materials. He was a member of the Council and a fellow of the Geological Society of America, a director of the American Petroleum Institute, and one of the founders and a past president of the American Assn. of Petroleum Geologists. Last year he was appointed regent of the Smithsonian Institution by President Eisenhower.

Mr. DeGolyer's association with AIME was a long and active one,

Memorial Resolution

EVERETTE LEE DEGOLYER

WHEREAS, with the passing of Everette Lee DeGolyer in Dallas, Texas, on December 14, 1956, the American Institute of Mining, Metallurgical, and Petroleum Engineers has lost one of its most distinguished members; and

WHEREAS, Mr. DeGolyer was, during his entire career, one of the most prominent engineers in the Mining and Petroleum profession, founder of a number of important oil companies, developer of many exploratory tools for the petroleum industry, and leading consultant in this field; and

WHEREAS, he had been a member of The American Institute of Mining, Metallurgical, and Petroleum Engineers since 1914 and an Honorary Member since 1951, and had served as a director of the Institute from 1921 to 1926 and from 1928 to 1929, and was president of the Institute in 1927; and

WHEREAS, he had received the Anthony F. Lucas Medal in 1940 and had received the John Fritz Medal in 1942 for his vision and leadership in developing and applying the art of geophysical exploration; therefore, be it

RESOLVED, that the American Institute of Mining, Metallurgical, and Petroleum Engineers record with deep sorrow the loss of this distinguished engineer, friend, and member; and be it further

RESOLVED, that this resolution be spread on the minutes of this meeting and a copy sent to the family of the late Everette Lee DeGolyer.

February 24, 1957 — AIME Board of Directors

and he contributed some 50 papers to AIME publications. A member since 1914, he was a director from 1921 to 1926 and from 1928 to 1929. He was the first chairman of the Petroleum Div., 1923-1925, and was president of the Institute in 1927. He received the AIME Anthony F. Lucas Medal in 1940 and the John Fritz Medal from the Four Founder Societies in 1942 for "vision and leadership in developing and applying the art of geophysical exploration." In 1951 he was elected an honorary member of AIME.

Mr. DeGolyer received many other honors, including the following honorary degrees: Doctor of Science from the Colorado School of Mines, Southern Methodist University, Tulane University, and Washington University; Doctor of Law from Trinity College; Doctor of Engineering from Princeton University; and Doctor, Honoris Causa, from the University of Mexico. He was a recipient of the Sidney Powers Memorial Award of the American Assn. of Petroleum Geologists and also received the first Distinguished Service Citation from the University of Oklahoma.

Mr. DeGolyer's rare capacity for simplifying complex problems so that they could be readily handled, influenced the thinking of many friends and associates. Likewise, his unusual ability in applying new concepts and methods to practical uses has had, and will continue to have, a lasting effect on the petroleum industry. Constant curiosity and love of research made his work a real pleasure to him, and the results brought him much fame and success. These qualities, which stimulated those around him to the full utilization of their talents, set him apart from other men.

Mr. DeGolyer is survived by his wife, Mrs. Nell Goodrich DeGolyer; three daughters, Mrs. John S. Maxson of Dallas, Mrs. George C. McGhee, and Mrs. Milton Arnold both of Washington, D. C.; a son Everette L. DeGolyer, Jr., of Dallas, and 13 grandchildren.

Albert E. White (Member 1919), retired director of the Engineering Research Inst., University of Michigan, died on Dec. 18, 1956. Born in Plainville, Mass., on March 12, 1884, he graduated from Brown University, which in 1925 bestowed upon him the honorary degree of Doctor of Science. After a year of graduate work in engineering at Harvard University, Mr. White joined the research department of Jones & Laughlin Steel Co., where he was in charge of research on iron ores, flue dust and firebrick. In 1911, he joined the faculty of the University of Michigan, becoming a full professor in 1919. During World War I, he was head of the Inspection Div., Ordnance Dept., U. S. Army. In World War II, he was chairman, Metallurgical Committee, National Defense Research Committee, and served on a similar committee of the Office of Scientific Research and Development. A past member of ASME and ex-president of the ASTM, Professor White's special interest was high-temperature properties of ferrous metals and alloys for use in power plants.

J. Preston Irwin (Member 1950) died on January 1, at the age of 67. Born in Houston, he graduated from Washington & Lee University, Lexington, Va., in 1909. Upon graduation he became professor of mathematics at Daniel Baker College, Brownwood, Texas, after which he joined the Southern Traction Co. as a draftsman. In 1917, Mr. Irwin became associated with Arthur G. McKee & Co., Cleveland, remaining with that company until his death, at which time his position was assistant chief engineer.

Frank Eichelberger (Member 1935) died suddenly of a heart attack in his home at Hayden Lake, Idaho, on Oct. 21, 1956. He was 71 years old. His outstanding mining career took him into ten countries and included important services to his industry in three wars. During those years he was associated with the construction of 16 different milling, smelting, and metallurgical plants. In recent months his principal interest was the operations of Conjecture Mines Inc., near his home in Idaho. A graduate of Michigan College of Mines in 1908, Mr. Eichelberger took his first mining job while still in school. During World War I, he supervised construction of one of the first commercial flotation mills in Helena, Mont. In the early 1950's he helped found American Chrome Co. and in 1952 went to South Korea as technical assistant to that government during the war.

Walter H. Jacobson (Member 1930) died on Dec. 19, 1956. A native of Perth Amboy, N. J., where he was born Aug. 8, 1897, Mr. Jacobson received his B.S. degree from Columbia University in New York. At the time of his death he was employed as metallurgist, Red Metal Dept., Nassau Smelting & Refining Co. on Staten Island, N. Y. He began his career as a chemist with American Smelting & Refining Co. located in Maurer, N. J., and in 1921 joined Tottenville Copper Co., S. I., N. Y. Mr. Jacobson's articles on analysis of tin and metallurgy of tin were published in *Metal Industry Magazine*.

Lynn H. DeSmyter (Member 1955) was killed in a plane crash on April 1, 1956. A native of Detroit, the 26-year-old metallurgist was a graduate of Wayne University. He had been enrolled in the University of Michigan as a candidate for the doctorate degree.

Fred C. Krebs, Jr. (Member 1953) died recently. Born 1930 in Syracuse, N. Y., he attended the University of Arizona where he received a B.S. degree in metallurgical engineering. During his summers as an undergraduate, he was employed by Commercial Travelers Mutual Accident Assn. of America. In 1954 Mr. Krebs became metallurgical engineer in charge of research and development of power metallurgy, Utica Drop Forge & Tool Corp. in Utica, N. Y.

NECROLOGY

Date Elected	Name	Date of Death
1941	Stanley L. Arnot	Unknown
1948	Frank J. Cole	Dec. 30, 1956
1954	Hale O. Davis	Unknown
1954	Max W. Dessau	Dec. 12, 1956
1936	Harold Stewart Elford	Unknown
1907	S. C. Fanenf Legion of Honor	Jan. 2, 1956
1950	J. Preston Irwin	Jan. 1, 1957
1930	Walter H. Jacobson	Dec. 19, 1956
1953	Marvin L. Kay	Dec. 7, 1956
1953	Fred C. Krebs, Jr.	Unknown
1942	A. M. Rippel	Dec. 12, 1956
1955	Eugene G. Saari	Unknown
1947	J. E. Settle	Sept. 14, 1955
1928	Edward W. Spottswood	1951
1919	Albert E. White	Dec. 18, 1956
1944	J. Lloyd White	Oct. 26, 1956

PROFESSIONAL SERVICES

Limited to AIME members, or to companies that have at least one AIME member on their staffs. Rates $40 per year per inch.

ALLOY METAL PRODUCTS, INC.
Consultants
Metallurgical by product, scrap and waste utilization
Rockingham Road **Davenport, Iowa**

MAX STERN
Consulting Engineer
Expert for Scrap Recovery and Shipwrecking — Modernization of Plants and Yards for Ferrous and Nonferrous Metal Scrap
10 East 40th St. New York 16, N. Y.

H. L. TALBOT
Consulting Metallurgical Engineer
Extraction and Refining of Base Metals Specializing in Cobalt and Copper
Room 330, 84 State St., Boston 9, Mass.

DR. E. TSUTSUMI
Registered Japanese Patent Attorney & Metallurgical Consulting Engineer
Patent Matters—Research . . . technical text translated from Japanese into English or vice versa. 2¢ per English word.
C P.O. Box 1545 **Tokyo, Japan**

COMING EVENTS

Mar. 10-16, EJC Second Nuclear Engineering and Science Congress, Convention Hall, Philadelphia.

Mar. 11-15, National Assn. of Corrosion Engineers, annual conference and exposition, Kiel Auditorium, St. Louis.

Mar. 13, AIME, NOHC Western Local Section, Rodger Young Auditorium, Los Angeles.

Mar. 13, AIME, NOHC Chicago Local Section, annual all-day meeting, Del Prado Hotel, Chicago.

Mar. 18-19, AIME Deep Drawing Steel Regional Meeting, sponsored by authorities on sheet steel, NOHC, and AIME Detroit Section, Rackham Building, Detroit.

Mar. 25-29, ASM And Others, Tenth Western Metal Exposition and Congress, Pan-Pacific Auditorium and Ambassador Hotel, Los Angeles.

Mar. 26, AIME, Connecticut Local Section. Speaker: P. C. Rosin, Universal-Cyclops Steel Corp.; subject: Metallurgical Aspects of Vacuum. Waterbury, Conn.

Mar. 29, 30, Effective Utilization of Engineering Personnel, Kellogg Center, Michigan State University, East Lansing, Mich.

Apr. 3, AIME Niagara Frontier Local Section, joint meeting with CIM. Speaker: W. J. Cook; subject: Milling and Smelting with Sudbury Nickel Ores. Tour of Port Colborne Works, International Nickel Co. Inc.; dinner, Barclay Hotel, Welland, Ont., Canada.

April 5, 6, AIME, Pacific Southwest Mineral Industry Conference. Sponsor: Nevada Local Section; cosponsors: San Francisco and Southern California Local Sections. Reno.

Apr. 8-10, AIME National Open Hearth Steel and Blast Furnace, Coke Oven, and Raw Materials Conferences, Penn-Sheraton Hotel, Pittsburgh.

Apr. 11-13, AIME, Pacific Northwest Regional Conference, Multnomah Hotel, Portland, Ore.

Apr. 16-17, AIME Regional Conference on High Temperature Alloys, Hotel Carter, Cleveland.

Apr. 22-24, CIM, annual meeting, Ottawa, Ont., Canada.

Apr. 24-25, Lead Industries Assn., annual meeting, Drake Hotel, Chicago.

Apr. 25, 26, American Zinc Inst. Inc., 39th annual meeting, Drake Hotel, Chicago.

May 5-9, American Ceramic Soc., annual meeting, Statler Hotel, Dallas.

May 6, AIME, NOHC Chicago Local Section, spring meeting, Phil Smidt's Restaurant, Chicago.

May 10, AIME, NOHC Eastern Section, plant trip, Colorado Fuel & Iron Corp., Claymont, Del.

May 10-11, AIME, NOHC Western Section, field trip, U. S. Lime Products Corp., Las Vegas, Nev.

May 12-16, Electrochemical Soc., Statler Hotel, Washington, D. C.

May 28-29, AIME, Reactive Metals Conference. Mining Branch sessions on May 28, Metals Branch sessions on May 28, 29. Ambassador Hotel, Los Angeles.

June 8, AIME, NOHC Southern Ohio Local Section, annual golf party, Middletown, Ohio.

June 23-28, ASTM, annual meeting, Chalfonte-Haddon Hall, Atlantic City, N. J.

Sept. 8-Oct. 9, Commonwealth Mining and Metallurgical Congress, British Columbia to Nova Scotia.

Oct. 6-9, AIME, Petroleum Branch, Dallas.

Oct. 9-11, Joint Solid Fuels Conference, ASME-AIME Coal Div., Chateau Frontenac, Quebec.

Oct. 18, AIME, NOHC Southern Ohio Local Section, annual meeting, Deshler-Hilton Hotel, Columbus, Ohio.

Oct. 30-Nov. 1, AIME Rocky Mountain Minerals Conference, Denver.

Nov. 4-6, AIME, IMD Fall Meeting, Morrison Hotel, Chicago.

Nov. 13, AIME, NOHC Buffalo Local Section, annual meeting, Hamilton, Ont., Canada.

Dec. 4-6, AIME, 15th Electric Furnace Steel Conference, Penn-Sheraton Hotel, Pittsburgh.

ADVERTISER'S INDEX

Ajax Electrothermic Corp. *
The Harry P. Bridge Co.

Ajax Engineering Corp. *
Eldridge, Inc.

Alloy Metal Products Inc. 322
The L. W. Ramsey Adv. Agency

American Bridge Div., U. S. Steel Corp. *
Batten, Barton, Durstine & Osborn, Inc.

American Machine & Metals Inc. Riehle Testing Machines Div. *
The L. W. Ramsey Adv. Agency

American Optical Co. *
Baldwin, Bowers & Strachan Inc.

Bailey Co., Wm. M. *
Downing Industrial Adv., Inc.

Basic, Incorporated *
The Griswold-Eshleman Co.

Bell Telephone Labs. *
N. W. Ayer & Son, Inc.

Buehler Ltd. *
Kreucker & Meloan, Inc.

Consolidated Electrodynamics Corp. Rochester Div. *
Charles L. Rumrill & Co., Inc.

Corhart Refractories Co., Inc. *
Doe-Anderson Adv. Agency

Davison Chemical Co. Div. W. R. Grace & Co. *
St. Georges & Keyes, Inc.

Dow Chemical Co. *
MacManus, John & Adams, Inc.

Electro Met. Div., Union Carbide & Carbon Corp. Third Cover
J. M. Mathes, Inc.

Ferro Engineering Co. *
C. A. Reece-Ind. Publicity

Frankel Co., Inc. *
Simons-Michelson Co.

General Electric Co., X Ray Dept. 319
Klau-Van Pietersom-Dunlap, Inc.

Great Lakes Carbon Corp. 324
Davis, Parsons & Strohmeier, Inc.

Harbison Walker Refractories Co. *
Downing Industrial Adv. Inc.

Hevi Duty Electric Co. *
Cramer, Coulson, Inc.

International Nickel Co. 316
Marschalk & Pratt

Jarrell-Ash Co. *
F. P. Walther Jr. and Assoc.

Jet Propulsion Laboratory Caltech *
Frank Barrett Cole, Adv.

Johns-Manville Corp. 311
J. Walter Thompson Co.

Kinney Mfg. Div. 321
The New York Air Brake Co.
Humbert & Jones, Inc.

Lectromelt Furnace Co. *
The Griswold-Eshleman Co.

Leitz, Inc., E. *
L. W. Frohlich & Co., Inc.

Michigan Chemical Corp. 387
Wesley Aves & Assoc.

Molybdenum Corp. of America 315
Smith, Taylor & Jenkins, Inc.

Morgan Construction Co. *
Davis Press, Inc., The

Mullite Works, Laclede-Christy Div. H. K. Porter Co., Inc. 385
St. Georges & Keyes, Inc.

National Carbon Co. Div. Union Carbide & Carbon Corp. *
William Esty Co. Inc.

National Research Corp. *
Sutherland-Abbott Adv.

The New York Air Brake Co. 321
Humbert & Jones, Inc.

North American Refractories Co. *
Clifford A. Kroening Inc.

Philips Electronics, Inc. *
Anders Associates Adv.

Ramtite Co., The *
Marsteller, Rickard, Gebhardt and Reed Inc.

Smooth-Harwood Co. 386
Allbright Associates Adv.

Smidth & Co., F. L. *
The Stuart Co.

Stokes Corp., F. J. *
The Aitkin-Kynett Co.

Swindell-Dressler Corp. *
Downing Industrial Adv., Inc.

Titanium Alloy Mfg. Div., National Lead Co. *
Comstock & Co.

Titanium Metals Corp. of America *
W. L. Towne Adv.

United States Graphite Co., The Fourth Cover
Price, Tanner & Willox, Inc.

U. S. Industrial Chemicals Co. Div. National Distillers Products Corp. *
G. M. Basford Co.

U. S. Steel Corp. 313
Columbia-Geneva Steel Div.
Tennessee Coal & Iron Div.
U. S. Steel Supply Div.
U. S. Steel Export Co.

Utica Drop Forge and Tool Div. of Kelsey Hayes Wheel Co. *
Zimmer, Keller & Calvert, Inc.

Whiting Corp. *
Waldie & Briggs, Inc.

Whittaker, Clark & Daniels, Inc. *
Charles W. Curtis Adv.

Wiley, John & Sons, Inc. 388A
Norman D. Waters & Assoc., Inc.

Wyman-Gordon Co. Second Cover
John W. Odlin Co., Inc.

* Previous issue.

For producing the New Chromium · Nickel · Manganese STAINLESS STEELS

ELECTROMET offers a variety of alloys designed to suit your specific needs

for Chromium additions

SIMPLEX *low-carbon ferrochrome*—chromium 63 to 66%, carbon max. 0.010% or 0.025%.

Low-carbon ferrochrome—Chromium 67 to 71%, ten carbon grades from 0.02 to 2% max.

Medium-carbon ferrochrome—chromium 66 to 70%, carbon 2.25 to 3%.

High-carbon ferrochrome—chromium 65 to 70%, five carbon grades from 4.5 to 7%.

Low-chromium, high-carbon ferrochrome—chromium 57 to 64% carbon 3.5 to 5%.

"EM" ferrochrome silicon—chromium 39 to 41%, silicon 42 to 45%, carbon max. 0.05%.

for Nitrogen additions

SIMPLEX *nitrogen-bearing, low-carbon ferrochrome*—in 2% and 5% nitrogen grades, containing 62 to 65% chromium and 60 to 63% chromium respectively.

Nitrogen-bearing, low-carbon ferrochrome—chromium 65 to 70%, in 0.75%, 1.25%, and 2% nitrogen grades.

Nitrogen-bearing, electrolytic manganese metal—containing approximately 93% manganese (metallic basis) and 6% nitrogen.

for Manganese additions

Electrolytic manganese metal—with minimum manganese content, on a metallic basis, of 99.9%.

Low-carbon ferromanganese—manganese 85% to 90%, six carbon grades from 0.07 to 0.50% max.

MANSILOY *alloy*—manganese 60 to 63%, silicon 28 to 31%, max. 0.07% carbon.

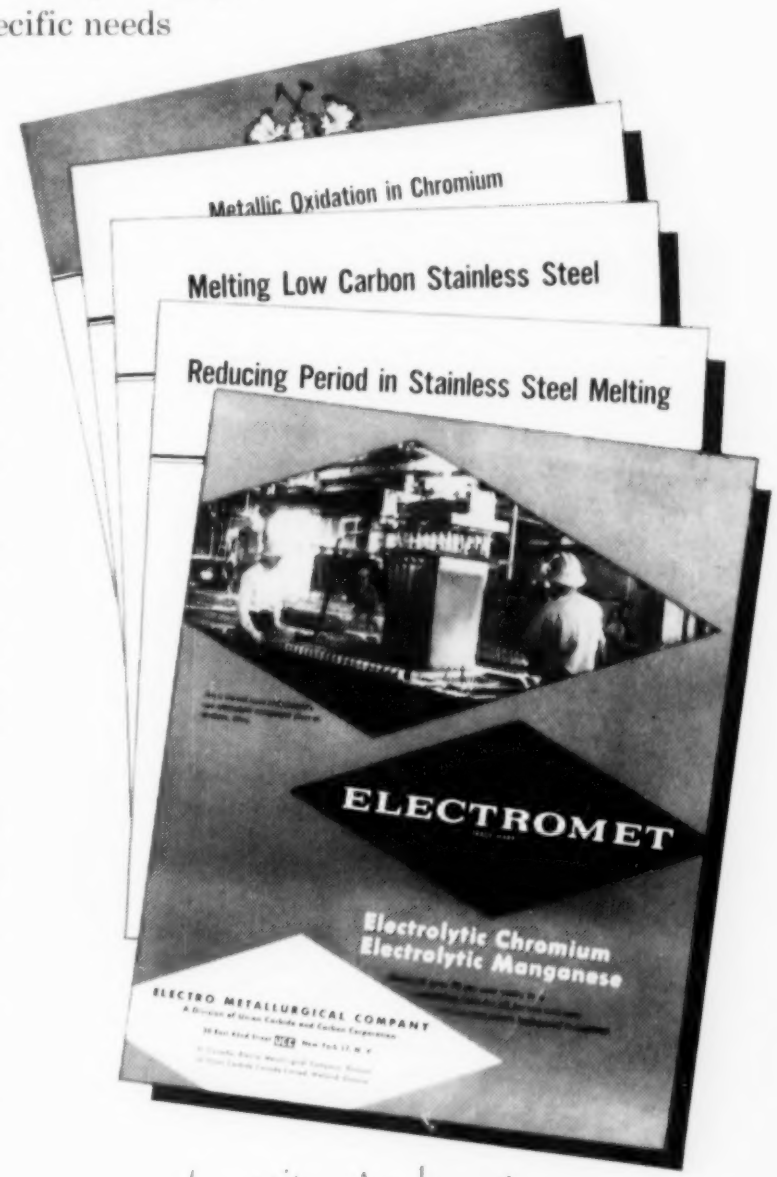
ELECTRO METALLURGICAL COMPANY
A Division of
Union Carbide and Carbon Corporation
30 E. 42nd St. UCC New York 17, N. Y.

Offices: Birmingham • Chicago • Cleveland
Detroit • Houston • Los Angeles
Phillipsburg, N. J. • Pittsburgh • San Francisco
In Canada: Electro Metallurgical Company,
Division of Union Carbide Canada Limited,
Welland, Ontario

Electromet
Trade-Mark

FERRO-ALLOYS AND METALS

"Electromet," "EM," "Mansiloy," and "Simplex" are registered trade-marks of Union Carbide and Carbon Corporation.



for additional information

Please contact the nearest ELECTROMET office. Ask for ELECTROMET's new 4-page brochure on electrolytic manganese and the booklets on melting low-carbon stainless steel.

SIPAC T.M. NON-CARBONACEOUS CORE COATING THAT PRODUCES SMOOTHER FINISHED CASTINGS

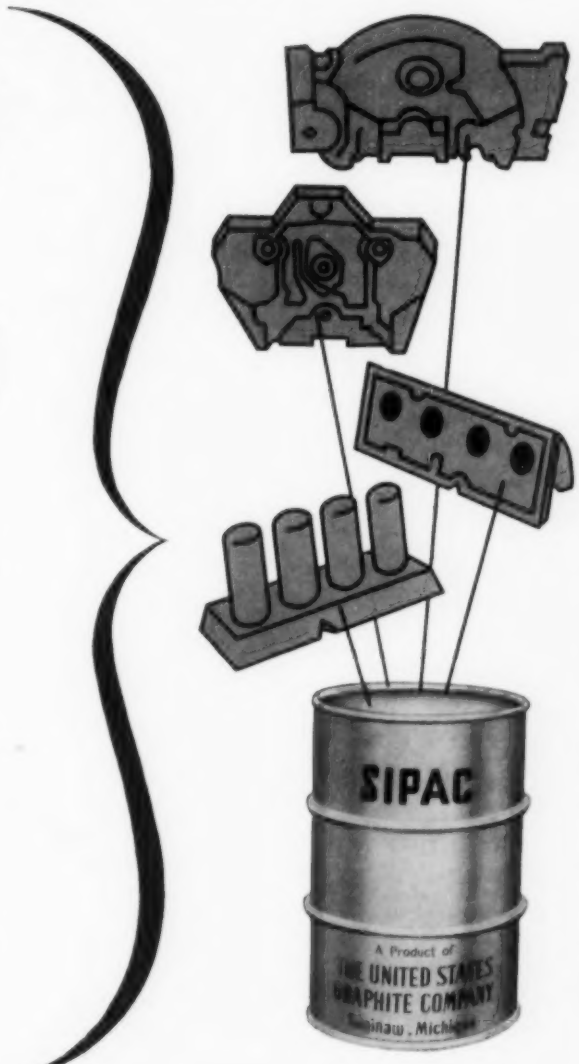
SIPAC United States Graphite Company's complete core coating, requires only the addition of water, and produces bright, gold-colored coating with fine, smooth surfaces—using any foundry sand.

SIPAC is non-carbonaceous and inert; will not react with any molten metal, including grey iron and steel. Clean to handle, its burnished gold color makes cores highly visible—a real help in placement of cores in the mold.

SIPAC costs less and gives improved casting quality. Resists flaking and completely seals core surfaces.

AVAILABLE in 55-gallon drums, (in paste form) ready for mixing and dilution to your desired Baume—even to a scale of 32—without settling.

WRITE TODAY for details about SIPAC or any other United States Graphite Company core and mold coatings.



228

THE UNITED STATES GRAPHITE COMPANY

DIVISION OF THE WICKES CORPORATION, SAGINAW 15, MICHIGAN

GRAPHITAR® CARBON-GRAPHITE • GRAMIX® SINTERED METAL PARTS • MEXICAN® GRAPHITE PRODUCTS • USG® BRUSHES